HUGHES

SUPPORT SYSTEMS

Contract Report No. 179586

Design Description Report

For

A Photovoltaic Power System For A Remote Satellite Earth Terminal

Prepared for:

The National Aeronautics and Space Administration

Lewis Research Center
Cleveland, Ohio 44135

Contract No. NAS 3-23862

Prepared By
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Hughes Aircraft Company
Long Beach, California 90810

January 1987

CONTRACT REPORT NO. 179568

DESIGN DESCRIPTION REPORT

FOR

A PHOTOVOLTAIC POWER SYSTEM FOR A REMOTE SATELLITE EARTH TERMINAL INSTALLED AT WAWATOBI, SE SULAWESI, FOR PERUMTEL REPUBLIC OF INDONESIA

In compliance with Exhibit "A"

of the Governing Contract

NAS3-23862

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JANUARY 1987

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1.0 FINAL DESIGN DESCRIPTION

1.1 SCOPE OF DESIGN DESCRIPTION REPORT

Subject photovoltaic (PV) power system has been installed as an adjunct to an agricultural school near the remote village of Wawatobi, some fifty kilometers from the City of Kendari, Sulawesi Tanggara, the south eastern province of the large northern island of the Republic of Indonesia.

The purpose of the system is to provide power for a satellite earth station and a classroom, both integral elements of the same complex. Functionally, the renewable energy developed by the system supports the video and audio teleconferencing systems as well as the facility at large. The earth station may later be used to provide telephone service to the nearby village.

The installation was made in support of the Agency for International Development's Rural Satellite Program, whose purpose has been to demonstrate the use of satellite communications for rural development assistance applications.

Within this broader mission, the objective of this particular PV power system is to demonstrate the suitability of a hybrid PV engine-generator configuration for remote satellite earth stations.

Subject design description report includes both general and detailed data concerning the design and specification of the PVs, the structures, the electronic apparatus, and the engine-generator. The report characterizes the overall system function, as well as those associated with the individual subsystems. The results of design verification testing are described, and the steps taken in planning and implementing an acceptable installation are detailed. On-site acceptance testing, and transfer of the fully operable system to the end-user, Perumtel, are also summarized. Design documentation, reflecting the final update after demonstrated operations is also included.

1.2 SYSTEM DEFINITION AND ABBREVIATIONS

The following are terms used in describing the major parts of the power system and their functions, as shown in Figures 1.2-1 "Mechanization of PV Power System", and 1.2-2 "PV Power System Block Diagram".

a. PV Module: A number of PV cells encapsulated under glass in a 2 ft. (0.60 m) by 4 ft. (1.21 m) frame. Each PV module develops about 66 watts at 15 V dc.

b. Array Panels: A frame containing four PV modules.

c. Source Circuits: Four PV modules wired in series developing a system voltage of about 60 V dc, also called a string.

d. Array Source Circuits: Two source circuits wired in parallel (8 PV modules total) producing about 528 watts peak power at system voltage, 60 V dc at 8.8 A dc.

e. Photovoltaic (PV) Array Field: The preferred system power source, the solar-electric generating system; consists of a total of six source circuits producing 60 V dc @ 26.4 A dc or 1584 W.

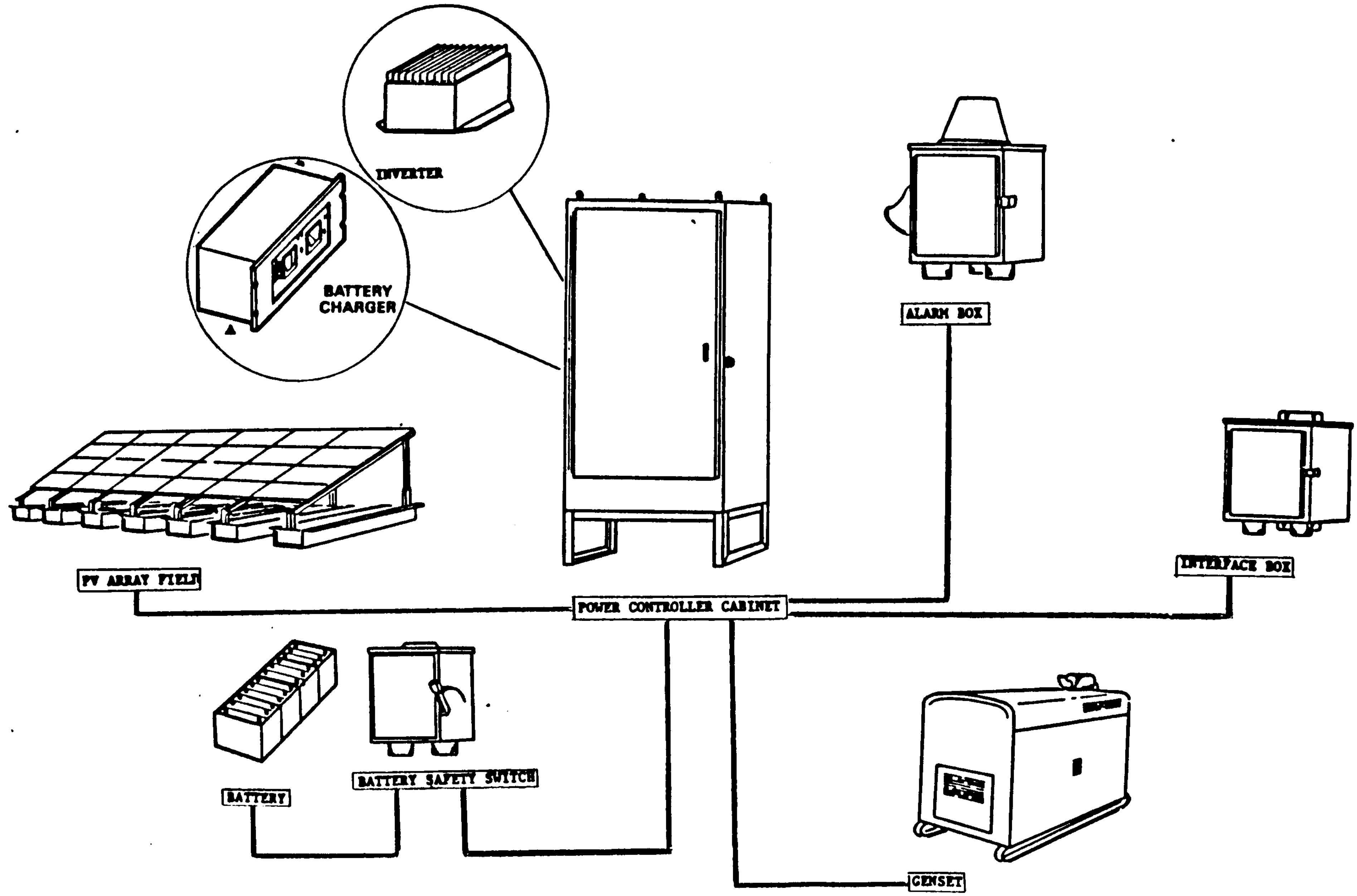


Figure 1.2-1. Mechanization of the PV Power System

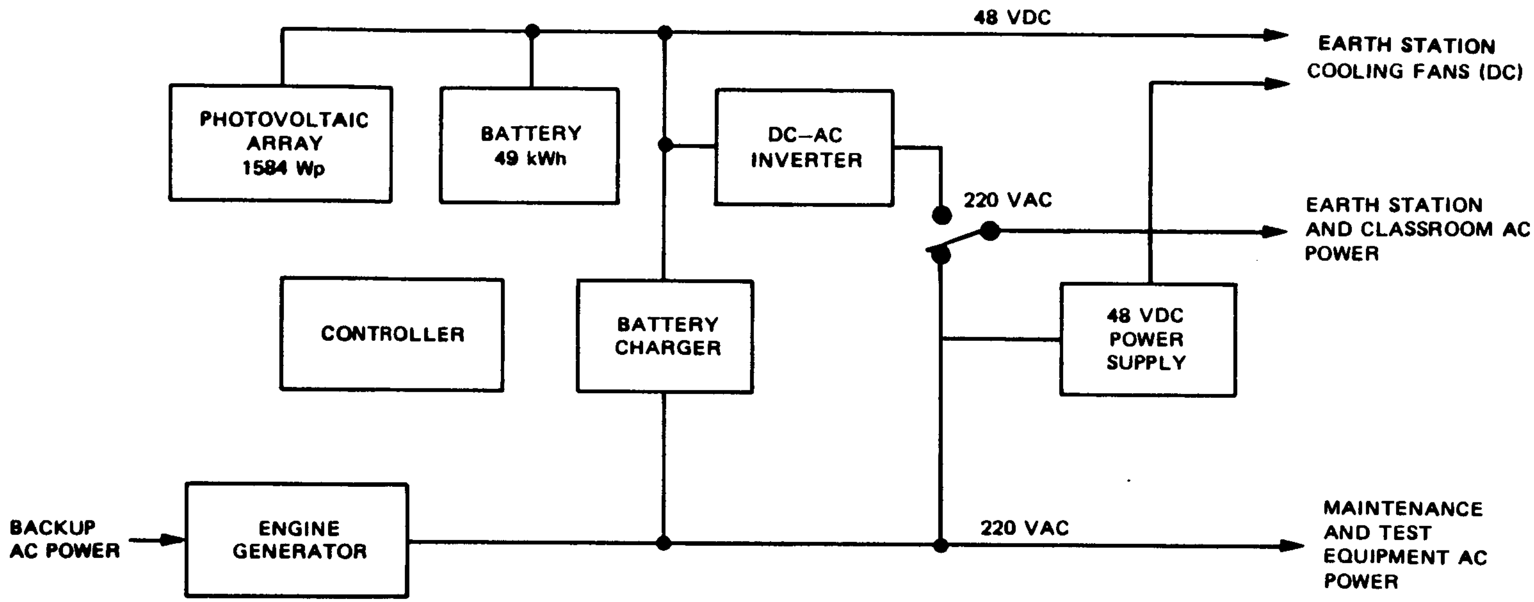


Figure 1.2-2. PV Power System Block Diagram

f. Power Controller: The master system control and protection subsystem.

g. Battery: Energy storage, permitting around-the-clock power delivery. A battery module is a factory package consisting of three two volt cells in series. This six volt module is the basic system building block.

h. GENSET: A diesel-electric generator, serving as automatic, on-call backup for the PV power generator, or alternatively support the earth station and classroom loads on a "stand-alone" basis.

i. Interface Circuits: 220 Vac at 50 Hz and 48 Vdc power to the satellite Earth Station and load.

j. Float Charge: A limiting voltage that allows maximum charging without overcharging batteries.

k. Taper Charge: The limiting of the charging current as the batteries reach approximately 90% charge.

ABBREVIATIONS AND ACRONYMS

AC	Alternating Current
ADC	Amperes Direct Current
AH	Ampere Hours
AMPS	Amperes (RMS AC)
BOS	Balance of System (All functional subsystems except PV modules.)
BSS	Battery Safety Switch
CBs	Circuit Breakers
DC	Direct Current
DD	Discharge Depth
DMM	Digital Multimeter
ESL	Earth Station Load
GENSET	Generator Set
HAC	Hughes Aircraft Company
KW	Kilowatt
KWP	Kilowatt Peak
MA	Milliampere
MOVs	Metal Oxide Varistors
NASA	National Aeronautics and Space Administration
OV	Overvoltage
P/N	Part Number
PC	Power Controller/Printed Circuit
PCP	Power Control Panel
POP	Power Output Panel
PSM	Power Switching Module
PU	Power Unit
PV	Photovoltaic
SCR	Silicon Controlled Rectifier
SEP	Solar Energy Project
UV	Undervoltage
V	Voltage
VAC	Voltage Alternating Current
VDC	Voltage Direct Current
VDC (pk)	Voltage Direct Current - peak array current

2.0 SYSTEM FUNCTION AND POWER FLOW

2.1 SUMMARY SYSTEM FUNCTION

The power system's functional flow, sensor signals and controls are shown in Figure 2.1-1 Schematic Diagram of PV Power System (with classroom and Earth Station). Systems ties with the Satellite Earth Station and classroom loads are also shown, as are the interfaces among the power subsystems.

The primary power source is the PV Array Field. It provides 48 VDC power. When there is insufficient solar sunlight for the PV array to support the loads and recharge the battery, the GENSET is commanded to turn on and deliver power.

The GENSET provides 50 Hz, 230 VAC power directly to the classroom load. It supports the Satellite Earth Station DC loads and recharges the battery through an AC to DC regulated Battery Charger. In the primary PV mode, the Battery and the PV Array supports the DC load directly. Earth Station and classroom AC power is obtained from a DC to AC solid state inverter. The GENSET and the PV power subsystem may be generating power simultaneously. In another mode, the control circuits permit the GENSET to power both loads directly, without either the Battery or the PV Arrays in the power circuit. These modes of operation are described in detail in Section 2.2 following.

2.2 OPERATING MODES

The system power and battery charge control algorithms establishing the operating modes are based upon two sets of critical battery terminal voltages at which particular events must, and/or have occured. Automatic system responses, both normal and protective shut-down, are based upon these thresholds. Figure 2.2-1 "Battery Voltage Trip Points for Major Control Events" summarizes these responses for the two sets. The left hand set is descending, listing critical occurances during the discharging state. The right hand set shows the thresholds during battery charging from either source, and the resulting control action. Particular levels listed are for a battery electrolyte temperature of 25 degrees Celsius and normal earth station and classroom loads.

With an adequate insolation level present, the solar panels generate sufficient power to supply the Earth Station and Classroom loads, and recharge the battery. This capability is implicit in the design specification of the PV panel complement relative to the anticipated load, the installation site, and the selected battery capacity.

The dominant or preferreed charging mode described in the paragraph preceeding is depcited in Figure 2.2-2 "MODE I/ AUTOMATIC: Operation from the "Preferred" PV Power Source with Automatic GENSET Backup". Referring to the initial figure of Section 2.0, Figure 2.2-1, the battery bus potential (under charge at an electrolyte temperature of 77 degrees F) falls normally in a range of 54.2 and 57.5 VDC. When the voltage climbs to 56.2 VDC, a transition occurs. Channel "B" photovoltaics, comprising aproximately 50% of the field output is automatically disconnected in the controller. Charging continues, but at one-half of the previous rate.

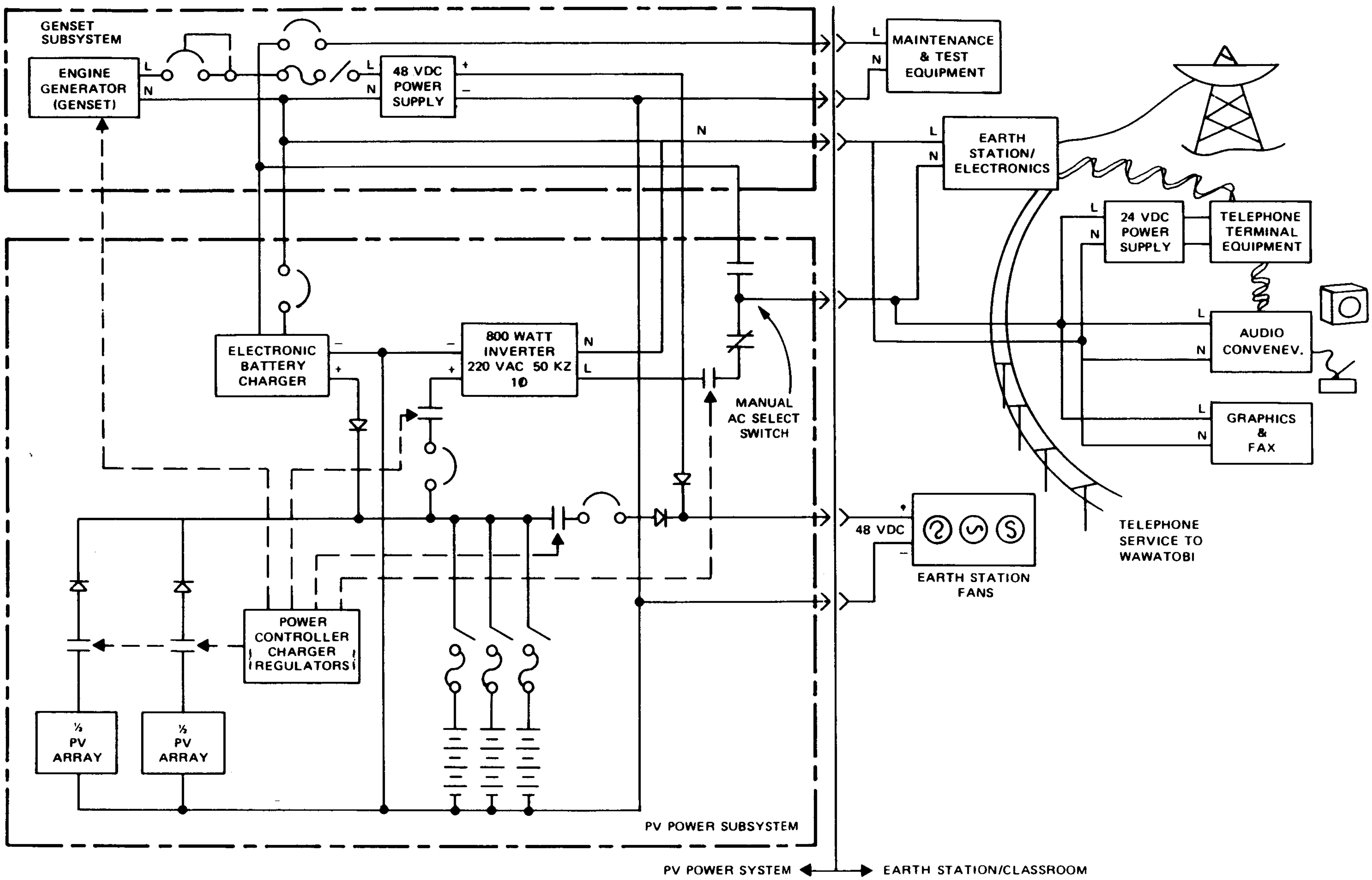
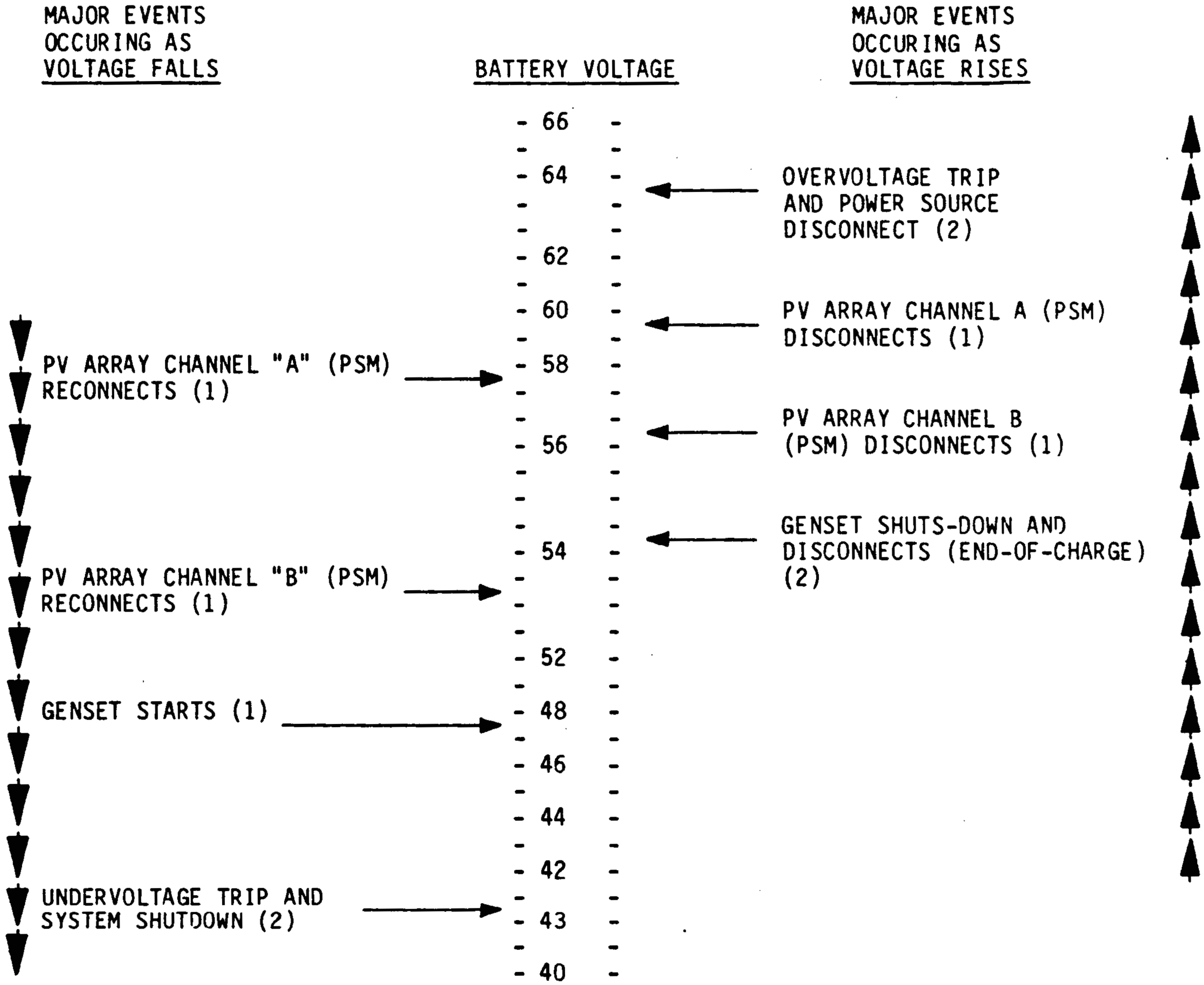


FIGURE 2.1-1 SCHEMATIC DIAGRAM OF PV POWER SYSTEM (SHOWING EARTH STATION AND CLASSROOM LOADS)



NOTES:

(1) AUTOMATIC STATE CHANGE AT PROPER VOLTAGE

(2) "LOCK-OUT"; REQUIRES MANUAL RESET

(3) ALL TRANSITION VOLTAGES GIVEN FOR 25^{0}C (77^{0}F); SEE TEXT

FIGURE 2.2-1 BUS VOLTAGE TRIP POINTS FOR MAJOR CONTROL EVENTS

Reduced rate charging continues until the battery potential reaches approximately 57.5 VDC. At this point the balance of the array power, the residual one-third dedicated to Channel "A" is disconnected. The discharge cycle now starts.

Under these conditions the GENSET is in standby, and its power production is not required. Figure 2.2-2 also depicts this state of operation in the "Automatic" mode. As long as the insolation is sufficiently high to overcome night-time losses and support the two loads, the system will continue on "automatic". Battery charging and powering the loads will continue until the battery is recharged. At this point charging is terminated by the controller and the battery enters a cycle float state.

The first discharge cycle takes place when the load current drain depletes the battery to a point where a portion of the panel complement is reconnected. Table 2.2-1 "Battery Voltage Trip Points for Major Control Events", illustrates this transition in the left hand descending arrow column.

With high levels of insolation the coulombic charge delivered will be to the battery, and its terminal voltage will continue to rise until the off/on cycling takes place. This float cycling continues as long as the net PV power generation is positive, and sustained sufficiently long to recharge the battery.

This automatic float cycling or "OFF/ON" may occur once or many times a day, depending upon the load, the insolation and the battery state-of-charge. The potential reduction in solar energy flux resulting from increasing cloud cover would be manifested by a lengthing of the charge "on" cycle relative to discharge (PV "off").

During storms, or under condition of heavy cloud cover, the insolation levels will be seriously degraded, if not interdicted. The control circuits will snse the sagging bus voltage; both Channelel "A" and "B" will be switched "ON", delivering the total output of the array then available. Unless the sunlight frequently breaks through the cloud cover, the controls will not cycle; the system will remain in the PV charging mode. (See Figure 2.2-3)

As the power balance shifts negatively, a shortfall develops; load power must be taken from the battery, and the latter may become the major, or perhaps the only supplier of power. These conditions are depcited in Figure 2.2-3 "MODE/AUTOMATIC: Operation from the "Preferred" PV Power Source, with Automatic GENSET Backup, and Degrading Solar Insolation." As long as the Battery is able to supply power to the Earth Station and the Classroom without being depleted below the critical voltage point, the GENSET will remain "OFF".

With no PV power the battery terminal voltage will drift downward toward the "GENSET START (1)" threshold as shown in Figure 2.2-1 "MODE I/AUTOMATIC: Operation under Conditions of Diminishing Insolation Requiring GENSET Power. The controller switches the GENSET to "ON" as illustrated in Figure 2.2-4

The GENSET will simultaneously support both the Earth Station and the Classroom load and recharge the Battery. If the weather is inclement and the insolation level low, the GENSET will cycle and supply the bulk of the energy. When the insolation rises to that of a clear sunlit day, the PV array will first share in the power production, basically assisting while the GENSET is still replenishing

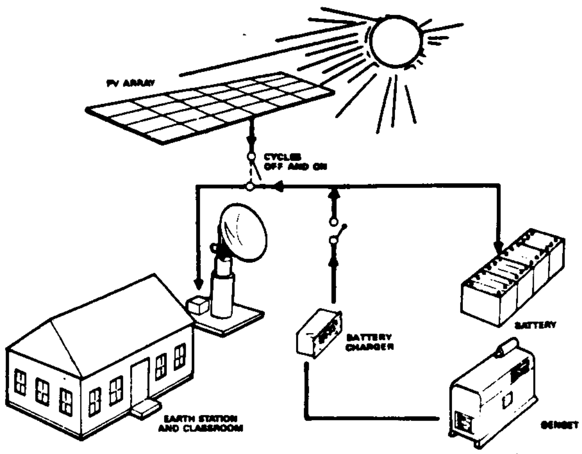


Figure 2.2-2. MODE I/AUTOMATIC: Operation from the "Preferred" PV Power Source, with Automatic GENSET Backup

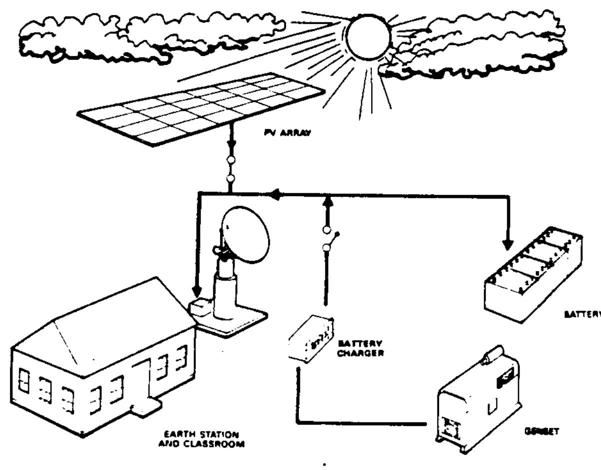


Figure 2.2-3. MODE I/AUTOMATIC: Operation from the "Preferred" PV Power Source, with Automatic GENSET Backup, and Degrading Solar Insolation

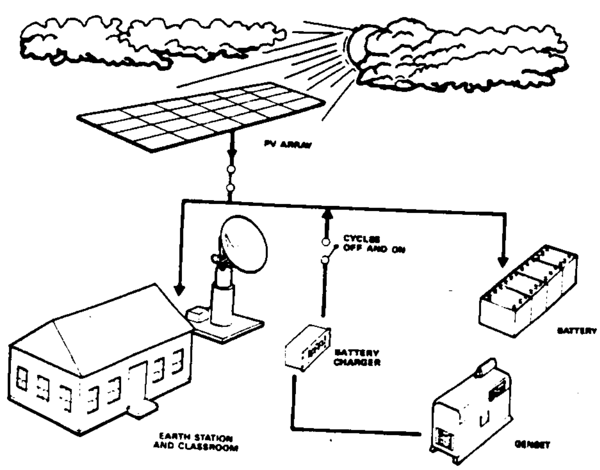


Figure 2.2-4. MODE I/AUTOMACIC: Operation Under Conditions of Diminishing Insolation Requiring GENSET Power

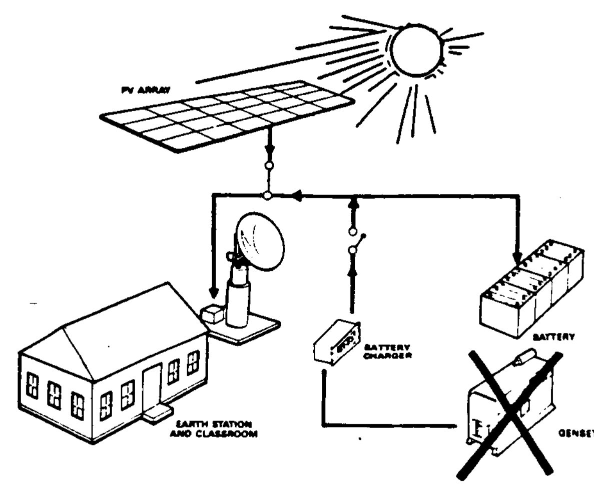


Figure 2.2-5. MODE I/AUTOMATIC: Randon GENSET Outage

the battery charge. The GENSET will not turn-off however until the critical control voltage shown in the bottom right hand column of Figure 2.2-1 is reached.

The sun may only shine sporatically for several days, or it may be so overcast that the solar contribution is virtually useless. In these circumstances the GENSET will cycle charge the Battery, periodically replenishing it. Since the GENSET/Battery power delivery capability is substantially greater than the continuous load demand, the battery will always cycle charge. This has proven to be an efficient charging regime, beneficial to GENSET longevity.

The system operates in the pure PV mode when the GENSET is "OFF-LINE" and its power is not available. This mode is depicted in Figure 2.2-5 "MODE II:/ Automatic Random GENESET Outage. The PV power supports both loads upon a continuous basis, with the battery float-cycling. With the normal expected site insolation, the float cycling will continue indefinitely as long as the loads remain within design limits. Figure 2.2-6 MODE II PV ONLY GENSET "OFF-LINE" illustrates this case. Figure 2.2-7 illustrates the circumstance with ongoing GENSET unavailability.

When the GENSET is not available, and the insolation inadequate, the controller will keep PV array connected continuously, delivering what power it is able. Under these conditions the battery will gradually decrease in terminal potential, indicating a continuous depletion of charge. Figure 2.2-8 shows the situation when the battery, the only source of energy, has reached its end point. The controller senses the undervoltage trip point and disconnects the nearly exhausted battery, thus shutting the system down. Figure 2.2-9 shows the charge cycling mode when the GENSET is the only power source. If the GENSET has to be used, this charge cycling method is much more beneficial to GENSET longevity than continuous support at low power.

2.3 POWER REGULATION AND CONTROL

The Power Controller Cabinet is the collection, conditioning, and distribution center for the system power. The power output of all the six PV Array source circuits are routed to the Power Controller Cabinet.

Prior to current summing at the battery bus, the source circuit power is partitioned, summed and sent through the two channels of the Power Switching Module (PSM) panel. These separated channels respond to the command signals of the battery charging and regulation controls; command signals float charge the battery in an off-on cyclic manner. The PSM also responds to protective shutdown commands originating in the Power Control Panel (PCP). The blocking diodes, crowbar, decoupling diodes, and diagnostic test points are also included in the PSM. The Power Controller Cabinet also houses the PCP and the Power Output Panel (POP). The PCP includes the master control circuits and displays of both AC and DC power circuits, and battery charge control. It includes automatic control logic that starts the GENSET when photovoltaic power is insufficient. These panels contain essentially all of the system controls and displays. The Power Controller Cabinet contains the terminal strips for termination of the array power collection source circuits. The load connectors carrying power to and from the battery are also included in the controller. The Power Controller Cabinet also houses the Instrumentation Panel, Battery Charger, the 50 HZ, 230 Vac Inverter and the AC ground fault interrupters.

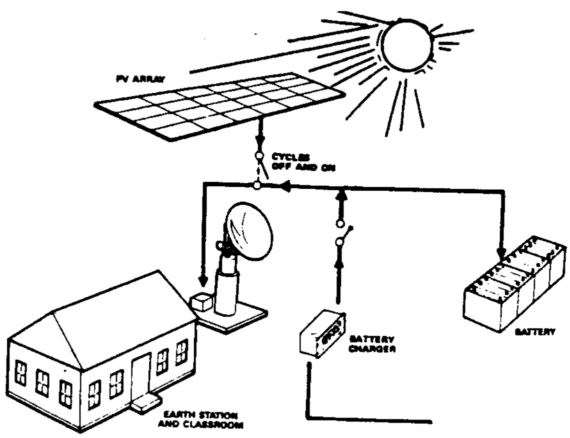


Figure 2.2-6. MODE II/PV ONLY: GENSET "OFF-LINE"

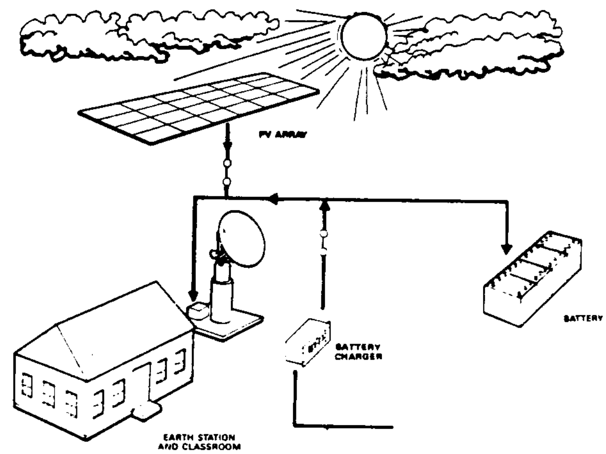


Figure 2.2-7. MODE II/PV ONLY: Continued MODE II Operation

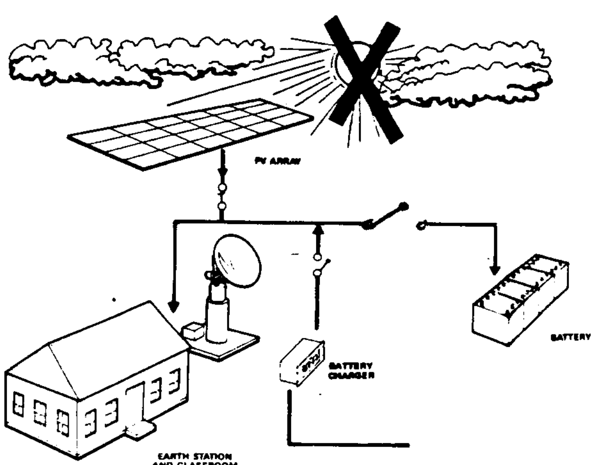


Figure 2.2-8. MODE II/PHOTOVOLTAIC POWER ONLY: GENSET OFF-LINE

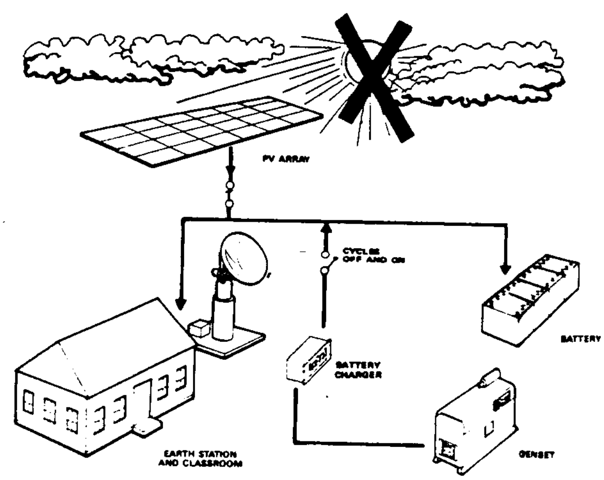


Figure 2.2-9. GENSET ONLY

2.3.1 Power Switching Module

The Power Switching Module (PSM) consolidates the input PV power from six 60 VDC source circuits, each producing approximately 260 watts peak. After passing through the blocking diode and test point network, the source circuits are partitioned into two control channels that form the bi-level charger/regulator.

The source circuits terminate on an input terminal strip, and metered power is delivered to the summing bus for charging the battery and supporting the Earth Station and classroom loads. The major elements of the PSM are:

a. Two each of two PV power control channels for battery charge regulation.

b. Crowbar relays for each channel (designated Channels A and B) for system and personnel protection.

c. Series power relays, performing the dual function of the series switching in the feedback control loop, and overvoltage disconnect.

d. Six crowbar steering diodes, one per source circuit, to maintain input PV current isolation for each source circuit.

e. Six blocking diodes, one per source circuit, to prevent current flow from the main power bus to the array in the event of a faulted PV array source circuit.

f. Metal Oxide Varistors (MOV) across the PSM PV power inputs to hold voltage surges to safe dielectric levels.

g. Six sets of diagnostic test points, provided in the form of voltage and current banana jacks; one set for each of the six circuits, provide for direct access measurements for troubleshooting system faults.

2.3.2 Power Control Panel

The Power Control Panel (PCP) consists of control electronics and the manual controls and displays for the power system. It includes the following:

a. The printed circuit board, which contains the voltage sensitive hybrid switches performing the following control protective functions: a) float charge; b) charge taper; c) undervoltage; d) overvoltage; e) GENSET load demand, and f) end-of-charge. It also contains the control power supplies for the DC ground fault detection circuits.

b. Summary system displays, indicators, and the battery current meter for instantaneous viewing system operational status, modes and performance.

c. The DC ground fault relay and crowbar circuits to protect personnel and equipment against catastrophic damage from faults.

d. Manual controls, mode select test switches, and transfer controls to allow personnel direct intervention of system operational modes and performance.

e. Pilot relays required to energize the main relays.

f. Interface circuits for battery charge control.

2.3.2 Power Output Panel

The Power Output Panel (POP) incorporates circuit breakers and the relays that control PV/GENSET power to the Earth Station and classroom loads. It includes the circuit breakers in the classroom AC and maintenance lines, the internal off-on controls for Inverter DC power input and output, and control of the Battery Charger power.

The POP also contains the current viewing resistors that provide precision DC sense voltages to the Instrumentation Panel. The continuous carry and fault trip ratings of the circuit breakers are coordinated with battery fusing ratings. The hermatic mercury displacement relays, each in series with a circuit breaker, provide manual control to each of the earth station distribution lines, 48 VDC and 230 VAC respectively.

Other sealed power relays are used in the transfer of the AC power source from Inverter to GENSET, and control of the AC power to the Battery Charger. The POP and PSM outputs are terminated on the battery summing buses in the POP. Cables from the POP terminates on a terminal block in the Interface Box. The three battery strings are connected with Supercon connectors mating with POP receptables. The POP also includes a large power diode for safely directing the Battery Charger current onto the main bus.

2.3.4 Instrumentation Panel

The Instrumentation Panel is divided into two equipment groups. One is the integrating ammeters and a single precision panel voltmeter. The other is a cluster of ampere-hour meters. The first group displays an instant summary of power system load demand, battery charging status, and power generation. The second group displays and records ampere hours delivered, consumed, stored, and returned from storage. Ampere-hour signals are derived from precision 50 millivolt shunts.

2.3.5 Battery Charger

The Battery Charger converts the GENSET AC power to DC power for charging the Battery. A visual display of the voltage and current being supplied to the battery is provided. The Battery Charger does not directly power the Inverter. The Battery Charger is a 2600 watt, SCR/TCR-10 power supply, supplied by Electronic Measurements, Inc. The vendor manual is included in the Service and Operating Instructions.

2.4 ENERGY STORAGE

Energy storage is provided by the battery subsystems. When more energy is produced by the PV Array Field than is being used by the loads, the surplus is diverted into the Battery. The Battery powers the system when the PC power is insufficient, serving as the primary source until the PV array receives enough insolation to power the loads. If the sun is not shining, the Battery continues to discharge until the GENSET takes over.

The basic battery module is a C&D type 3KCPSA-5, three series cell packs, rated 220AH (8 hr. rate). The battery or 24 2volt cells consists of three parallel strings, each string containing eight modules in series. For more information about the batteries refer to the C&D Stationary Battery Installation and Operating Instructions manual provided in Volume IV of the Operating and Service Instructions.

2.5 BACK-UP GENSET POWER

The GENSET is an air cooled diesel engine generator that is used to provide PV Array Field back-up power. When the PV Array fails to deliver the necessary power, and the Battery has reached a predetermined depleted state-of-charge, the GENSET will automatically start and provide the required power to both of the loads and to recharge the Battery. It will automatically shut down when the Battery has reached a state-of-charge of about 90%. The GENSET is a product of the Onan Corporation. Its technical manual is included in the O&M Manuals.

2.6 EARTH STATION INTERFACE

The interface electrical connections to the Satellite Earth Station are provided for located in the Interface Box which is approximately 30 ft. from the PV Power equipment enclosure. The inputs to the Interface Box are $\pm$ 48 VDC and 230 VAC.

2.7 CONTROL LOGIC AND SENSORS

Functional operations of the power system are divided between control and sensor functions. The control functions contain the circuitry that carry out the instructions, interpret each instruction, and apply the proper signals to the power system elements. These signals are sometimes manually initiated. The sensor functions contain the circuitry which determine circuit performance status and/or deviations from a reference and convert them into electrical instructions.

2.7.1 Sensing of Critical Voltages

The Battery Charger's regulator is a comparator relay circuit termed a voltage sensistive hybrid switch (VSHS). It performs the major control functions. A simplified block diagram of the multilevel charge control float cycle regulator using two VSHSs is given in Figure 2.7-1. VSHSs are also used for protection from abnormal voltages on the DC bus. The relay of each of the two PV array channels energizes when a critical descending or ascending voltage point is reached. A VSHS is also used to turn on the GENSET when, under discharge, the battery voltage becomes too low. Another VSHS turns off the GENSET when the Battery has recharged, and the voltage has risen to a safe level. These VSHSs are adjusted, calibrated, and interlocked to automatically perform the major control functions.

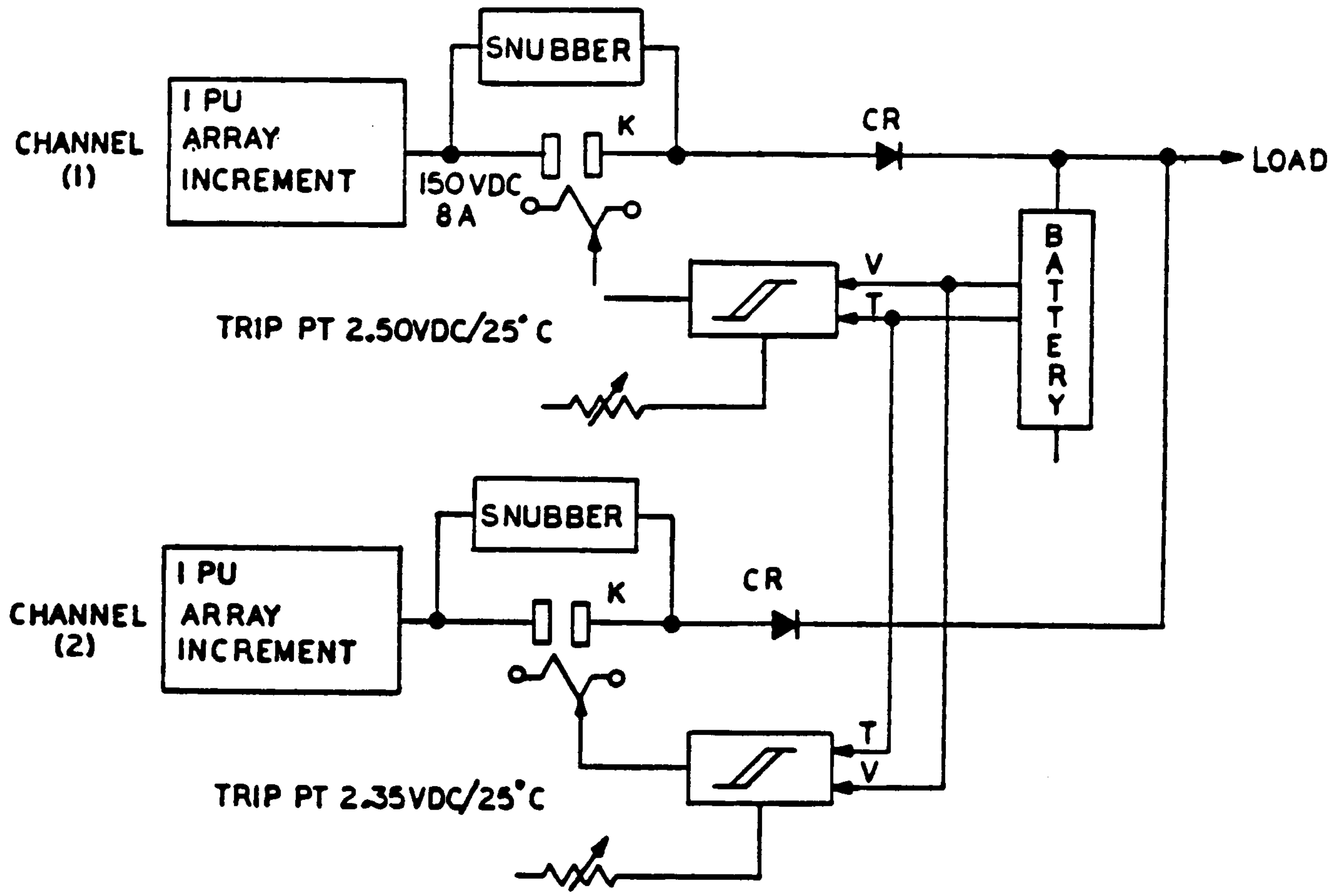


Figure 2.7-1. Multilevel Charge Control

2.7.2 Voltage-Sensitive Hybrid Switches

Two VSHSs, coupled with (PSM) channel A and B series power control assemblies form the Battery Charger/Regulator. Figures 2.7-2 and 2.7-3 are simplified schematics of the float charge and charge taper VSHSs, respectively. In this regulator, different upper-boundary voltage limits are independently assigned to the VSHS controlling each of two channels of the PSM. The printed circuit control board includes eight VSHS channels, six of them dedicated to the control functions, Channels A/B REG, UV/OV trip, GENSET load demand, and end-of-charge (see Figure 2.7-4). For charging the battery, the output power of the six PV source circuits is divided and merged into two separate regulator channels. One-half of the PV source circuits is assigned to float channel A, the remaining half is assigned the charge-taper channel B. If a battery string or a PV source circuit is lost, the system will continue to function, but at a reduced output with one PV source circuit deenergized.

When the PV source circuits are producing power, the battery voltage will rise as the charge is being replenished. The PV source circuits continue charging the battery while also supporting the Earth Station load. During periods of low insolation, a power defficiency may periodically occur. The battery, after supporting the load for a set period, will begin to run out of energy. At a pre-determined point, the GENSET will turn on and recharge the battery and support the earth station load.

During charging, when a bus voltage of 56.4 VDC (2.35 volts per cell) at 77^{o}F (25^{o}C) is reached, the channel B relay is de-energized. Charging continues at half the previous rate since only channel A remains activated. When the battery potential reaches 60 VDC (2.50 volts per cell) 77^{o}F (25^{o}C) the float comparator changes state, cutting off the PV source circuit charging current by releasing the power relay of PSM channel A. These preset voltage cut off points are corrected automatically for changes in battery electrolyte temperature. They can also be independently adjusted in the event the control and protective setpoints need to be corrected or refined.

Hysteresis is built into the VSHS comparator circuits by the feedback path between the plus (+) comparator input and the output. This may be varied by changing the setting of a potentiometer in the positive feedback loop. The hysteresis creates an offset between the on and off voltage thresholds. This ensures that two stable operating states will exist. As an example; assume that channel A has cut off at a bus voltage of 60 VDC or 2.5 VDC per cell. The loads are then supported by battery power. With 4 volts hysteresis, a reverse transition to the charge cycle will not take place until the bus voltage has been lowered to 56 VDC (2.33 V per cell). At this transition point, the float comparator again changes states and starts charging. The charge-taper comparator behaves similarly, except through a lower voltage window. The status of the control elements for both of these charge-regulating functions are included as Tables 2-1 and 2-2.

In the event of an open circuit failure in either of these charge regulating comparators, the system will continue to operate, but at reduced power. The impacts of the various failure combinations in the PV regulator are summarized in Table 2-3.

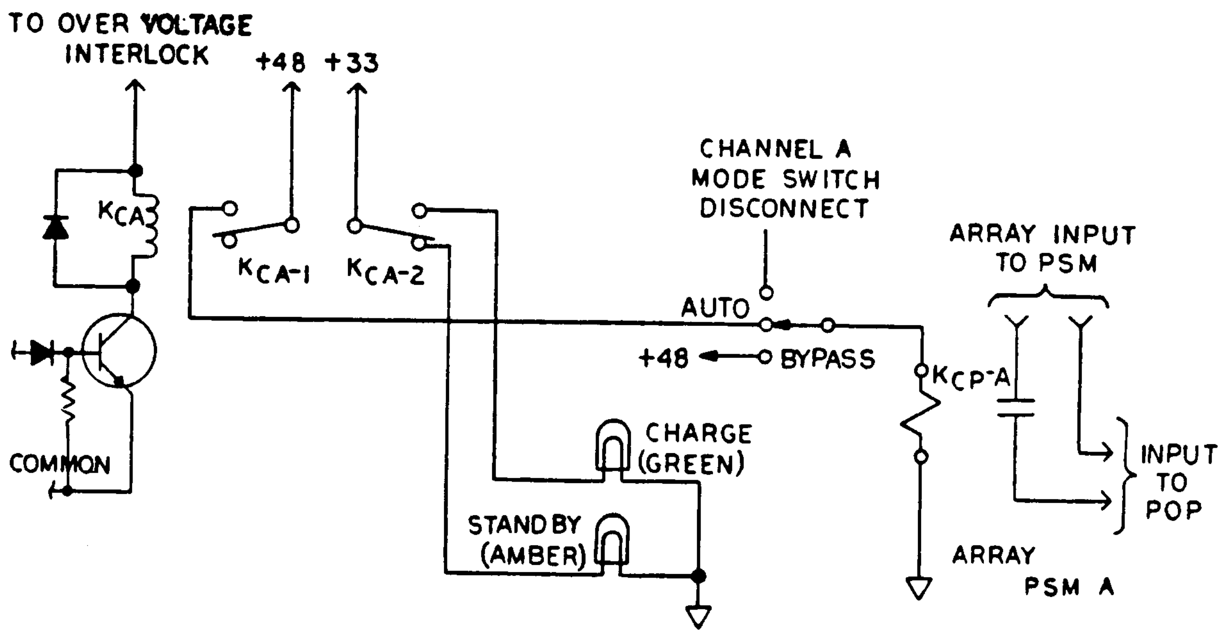


Figure 2.7-2. VSHS-A Float Charge

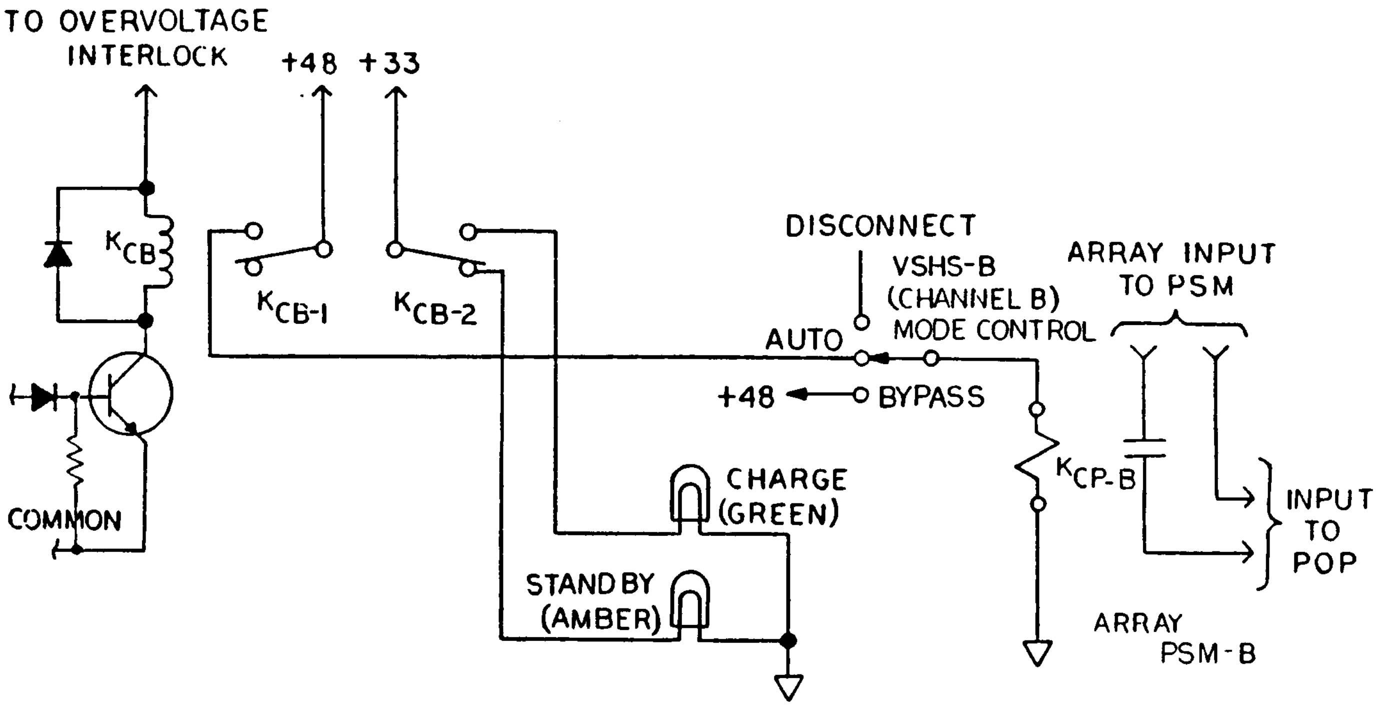


Figure 2.7-3. VSHS-B Charge Taper

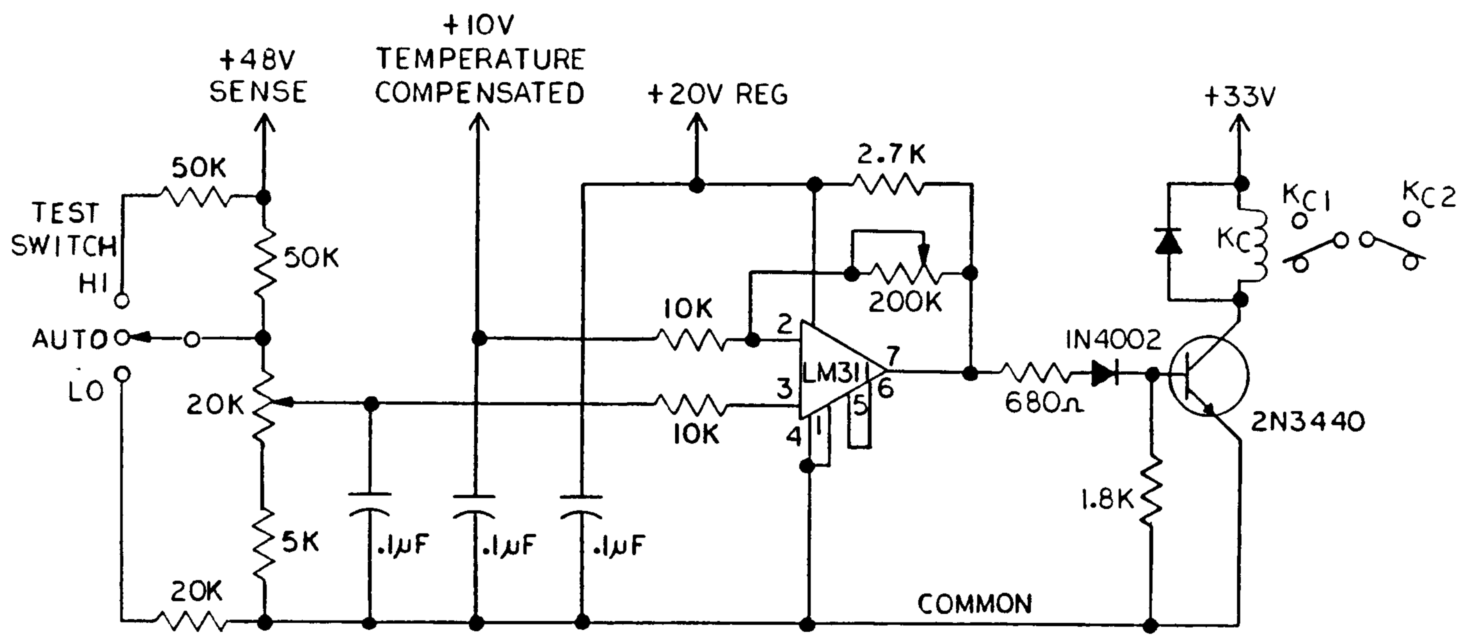


Figure 2.7-4. Channel A, B, Overvoltage; GENSET Demand; and End-of-Charge

Table 2-1. Float Charge Comparator (VSHS-A) Truth Table

Control Function	Control State		
	Float Charging Cycle	"Off" Mode After Array Power is Turned Off	Voltage at Which Array Power is Turned Back On
Critical Battery Voltage	$\leq$ 60 VDC	$\geq$ 57.5 VDC (initial)	$\leq$ 57.5 VDC (initial)
Comp. A Input (Neg)	Low	High	High
Comp. A Output	High	Low	Low
Static Switch	Closed	Open	Open
Coil Kc-A	Energized	De-energized	De-energized
KcA-1 NO *	Closed	Open	Open
KcA-1 NC **	Open	Closed	Closed
KcA-2 NO *	Closed	Open	Open
KcA-2 NC **	Open	Closed	Closed
Status Lamp	Green "ON"	Amber: Stand-by "ON"	Amber to green after transition
Kpsm-A Coil	Energized	De-energized	De-energized
Kpsm-A No Contact	Closed	Open	Open
Array Power	Power on "GO" (charging)	None (power interrupted)	No power until transition occurs

* (NO) Normally Open
** (NC) Normally Closed

Table 2-2. Charge Tape Comparator (VSHS-B) Truth Table

Control Function	Control State		
	Taper Charging Cycle (Array Power On)	"Off" Mode After Array Power is Turned Off	Voltage at Which Array Power is Turned Back On
Critical Battery Voltage	$\leq$ 56.4 VDC	$\geq$ 56.4 VDC (initial)	$\leq$ 53.52 VDC (initial)
Comp. B Input (Neg)	Low	High	High
Comp. A Output	High	Low	Low
Static Switch	Closed	Open	Open
Coil Kc-B	Energized	De-energized	De-energized
KcB-1 NO *	Closed	Open	Open
KcB-1 NC **	Open	Closed	Closed
KcB-2 NO *	Closed	Open	Open
KcB-2 NC **	Open	Closed	Closed
Status Lamp	Green "ON"	Amber: Stand-by "ON"	Amber to Green after transition
Kpsm-B Coil	Energized	De-energized	De-energized
Kpsm-A No Contact	Closed	Open	Open
Array Power	Power On "GO" (charging)	None (power interrupted)	No power until transition occurs failure

* (NO) Normally Open
** (NC) Normally Closed

Table 2-3. Impact of PV Regulator Failures

Dominant Failure Mode	Secondary Failure Mode	Sympathetic Failure Mode
1. VSHS A/KpSM-A	Short. 1/2 (50%) of array always ON.	Battery will probably overcharge.
2. VSHS A/KpSM-A	Open. 1/2 (50%) of Array power Only available.	Without some load shedding, battery may gradually run down.
3. Comp. B/KpSM-B	Short. 1/2 (50%) array power always ON.	Battery may overcharge.
4. Comp. B/KpSM-B	Open. Loss of 1/2 (50%) of available PV power.	Same as No. 2.
5. Both Mode (1) & (3) above occur	Array power full ON and controlled.	Battery will overcharge during high insolation periods.
6. Both Mode (2) & (4) above occur	No PV power available.	Load will be supported by storage only until GENSET starts.
7. Mode (1) & (4) simultaneously	Continuous (unregulated) PV power at 1/2 (50%) of peak available level.	Appears like a smaller unregulated array; state is a function of insolation and load.
8. Mode (2) & (3) simultaneously	Same as No. 7.	Same as No. 7 above.

2.7.3 Temperature Compensation of the Charging Reference

The charging control algorithm for lead acid batteries is temperature dependent. The float voltage for lead calcium cells must decrease with rising electrolyte temperature, at a rate of 5 millivolts per ^{o}C per cell, from the 77^{o}F (25^{o}C) value. This protects the battery against overcharging damage at high temperatures. Battery conductivity decreases with decreasing temperature. The float potential must increase (at 5 millivolts per ^{o}C per cell) below an electrolyte temperature of 77^{o}F (25^{o}C). A potential of 2.45 to 2.50 volts per cell is necessary for float charging batteries with 1.300 specific gravity electrolyte. For the 24 cell complement, the charging voltage is therefore set for a float voltage of 60 VDC at 77^{o}F (25^{o}C). This voltage automatically reduces at a rate of 300 millivolts for each ^{o}C rise and correspondingly increases at the same rate for each ^{o}C fall. This temperature compensation of both the float charge comparator (VSHS-A), and the charge taper comparator (VSHS-B), is accomplished by shifting the reference voltage applied to the non-inverting input of each comparator. The actual probe is mounted on the negative cell stud of a battery string. This temperature is essentially that of the electrolyte of the sample cell.

2.7.4 Undervoltage Trip

The undervoltage trip circuit automatically removes all loads when a critical battery undervoltage is reached. It will be reached when the GENSET has failed to start, or the Battery Charger has faulted. If the GENSET and/or Battery Charger are not operating, this emergency mode shutdown can also be triggered from any of the causes listed below, or a combination of them. Figure 2.7-5 shows the undervoltage VSHS Functional Diagram.

a. A regulator failure of the open circuit type.

b. Failure of the PV Array to deliver power due to loss of sunlight, or gross malfunctions.

c. Sustained load overcurrent failing to trip the circuit breakers.

If this protective function is bypassed or fails, and the GENSET is not started, the battery will continue to discharge until no energy remains. Undervoltage trip is a lockout function. Table 2-4 summarizes the control states of the various undervoltage control.

2.7.5 Emergency Overvoltage Trip

This control protects the system and the load from overvoltages on the bus. It provides safety back-up to the float charge VSHS-A. The highest safe voltage is the preset float voltage. This voltage is approximately 60 VDC, or 2.50 V per cell at 77^{o}F (25^{o}C). Any sustained voltage in excess of this value is a positive indication of something significantly wrong in the electrical subsystems. The preset trip (62 VDC) disconnects the PV source circuits and shuts down the GENSET.

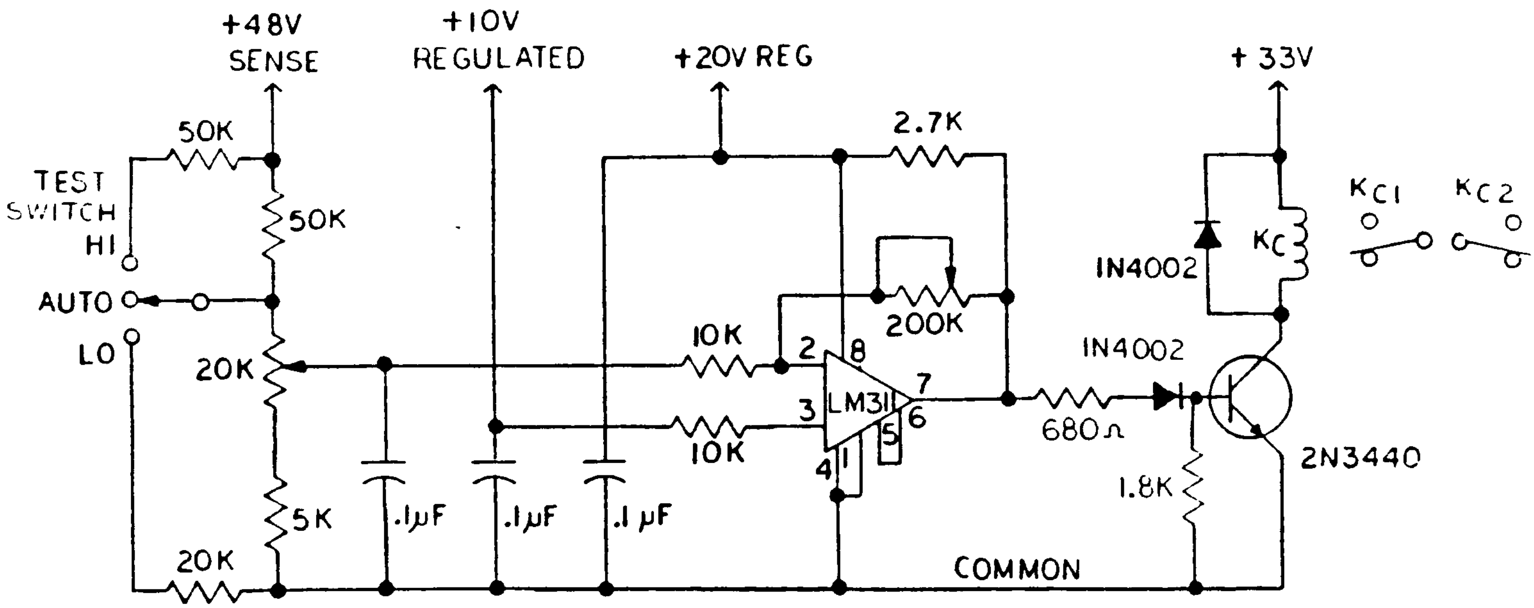


Figure 2.7-5 Undervoltage VSHS

Table 2-4. Undervoltage (UV) Trip Truth Table

Control Function	Control Status		
	(V Batt Normal) Reset Not Yet Made	In Tolerance Operation (V Batt Normal)	Protective UV Trip
Battery Voltage	Greater Vuv (trip)	Greater than Vuv (trip)	Less than Vuv (trip)
Critical Voltage	Greater than 43.2 Volts	Greater than 43.2 Volts	Less than 43.2 Volts
Comp C (+) Input	High	High	Low
Comp C (-) Input	Low	Low	High
Comp C Output	High	High	Low
SSW Status	Off	Closed	Off
KC Coil	De-energized	Energized	De-energized
NO Kc-1	Open	Closed	Open
NC KC-1	Closed	Open	Closed
Load Relay Coil	De-energized	Energized	De-energized
All POP load relay contacts	Open	Closed	Open
Aural/visual alarm interlock	Deactivated when V bus has re-covered to normal limit	Deactivated	Closed; alarm activated

An overvoltage is traceable to several causes:

a. Main bus potential rises to the open circuit voltage of the PV Array Field. This indicates that the batteries were disconnected from the bus, either by blown fuses or as the result of manual intervention. Erratic cycling would be observed; potentially destructuve transients and sustained overvoltage could be present on the output bus.

b. Terminal voltages above 62 VDC and high levels of battery overcharging (gassing, etc.). This indicates that the PV charger regulator circuits or the Battery Charger has malfunctioned. Action must be taken at once to avoid battery destruction.

c. Faulted GENSET Voltage Regulator. This malfunction may harm the Battery Charger and may create the additional problem of dangerous AC voltages.

Manual reset is always required to clear an overvoltage trip; the fault must be cleared prior to reactivation of the system. The control responses is shown in the Table 2-5.

2.7.6 GENSET Demand Control Function

The GENSET must be started, brought on-line, and the battery recharged whenever the battery state-of-charge is depleted below a safe level. Either manual or automatic start up may be selected on the Power Control Panel. Table 2-6 identifies the control states for various control functions. Figure 2.7-6 is a schematic of the GENSET Demand function. A terminal voltage of 46.8 VDC is used as the transition point at which then battery must be recharged and the load supported by the GENSET. Automatic start-up of the GENSET and Battery Charger occur when the battery state of charge drops to this voltage. With the GENSET and Battery Charger operating, the voltage rises substantially above the 1.95 V per cell (or 48.6 VDC) at 77°F (25°C) threshold. The circuit turn-on is therefore latched to avoid recycling. This latch is released by an interlock in the output control circuit of the end-of-charge comparator VSHS-F.

If the GENSET fails to start, the battery will simply continue to discharge until the undervoltage comparator in VSHS-C is tripped.

An audible warning is sounded to indicate that the GENSET failed to start. The GENSET may be manually started at any time by switching to that operational mode.

2.7.7 End-of-Charge Function

The GENSET must be shut off in order to stop recharging the Battery and supporting the Earth Station and classroom loads when the preset state-of-charge has been restored to the Battery. This point will be determined by the on-charge battery voltage. When this potential reaches 55 VDC (2.29 V per cell) at 77°F (25°C), the GENSET will shutdown. Automatic shutdown takes place as the result of a state of change in VSHS-F.

Table 2-5. Emergency Overvoltage (OV) Trip Truth Table

Control Function	Control State		
	Emergency State; Battery Voltage Greater Than OV Trip Limit	Battery Voltage Normal; OV Trip t Limit Not Exceeded	Battery Voltage in Tolerance; Prior to Over-voltage Reset
Input (+) Line	Battery Voltage ex-ceeded trip limit	Battery Voltage in tolerance	Battery Voltage in tolerance
Critical Battery Voltage	> 62.4/ VDC	< 62.4 VDC	< 62.4 VDC
Comp D Input	High	Low	Low
Comp D Output	Low	High	High
SSW-D Status	Open	Closed	Open
KCD Coil	Off	Energized	Off
KCD-1 NO Contact *	Open	Closed	Open
KCD-1 NC Contact **	Closed	Open	Closed
KCD-2 NO Contact *	Open	Closed	Open
KCD-2 NC Contact **	Closed	Open	Closed
Warning Indicator (OV)	On [OV]	Off (Normal)	On [OV]
K (UV) Coil	Off	Energized	Off
I Inv (Inv Load)	Open	Closed	Open
K ESL (DC Load)	Open	Closed	Open
KpsmA, KpsmB	Off	On	Off
DC to Inverter	Off	On	Off

* (NO) Normally Open
** (NC) Normally Closed

Table 2.5. Emergency Overvoltage (OV) Trip Truth Table (Continued)

Control Function	Control State		
	Emergency State; Battery Voltage Greater Than OV Trip Limit	Battery Voltage Normal; OV Trip t Limit Not Exceeded	Battery Voltage in Tolerance; Prior to Over-voltage Reset
GENSET Fuel Valve Solenoid and Start Circuit Open	Off	On	Off
GENSET	STOPPED	Running (GENSET "ON" Mode)	

Table 2.6. GENSET Demand Truth Table

Control Function	Control State: Before Start Command	Control State: Normal Operation (GENSET not needed)	Control State: GENSET Start Command After Transition
Critical Battery Voltage	More than 46.8V and less than 55 VCD	More than 46.8 VDC	Below 46.8 VDC
Comp-E Input (Neg)	High	High	Low
Comp-E Output	Low	Low	High
Transistor	Off	Off	On
Coil KCE	De-energized	De-energized	Energized
KCE-1 NO *	Closed	Open	Closed
KCE-1 NO *	Open	Closed	Open
KCE-2 NO *	Closed	Open	Closed
KCE-2 NO *	Open	Closed	Open
Status Lamp	GENSET Off	None Off	GENSET On
Solenoid GENSET Start	Off	De-energized Solenoid	Energized momentarily
GENSET Shut Off		In Force	Open
Audible/Visual Alarms	Deactivated	Deactivated	Deactivated except if start-up failure

* (NO) Normally Open

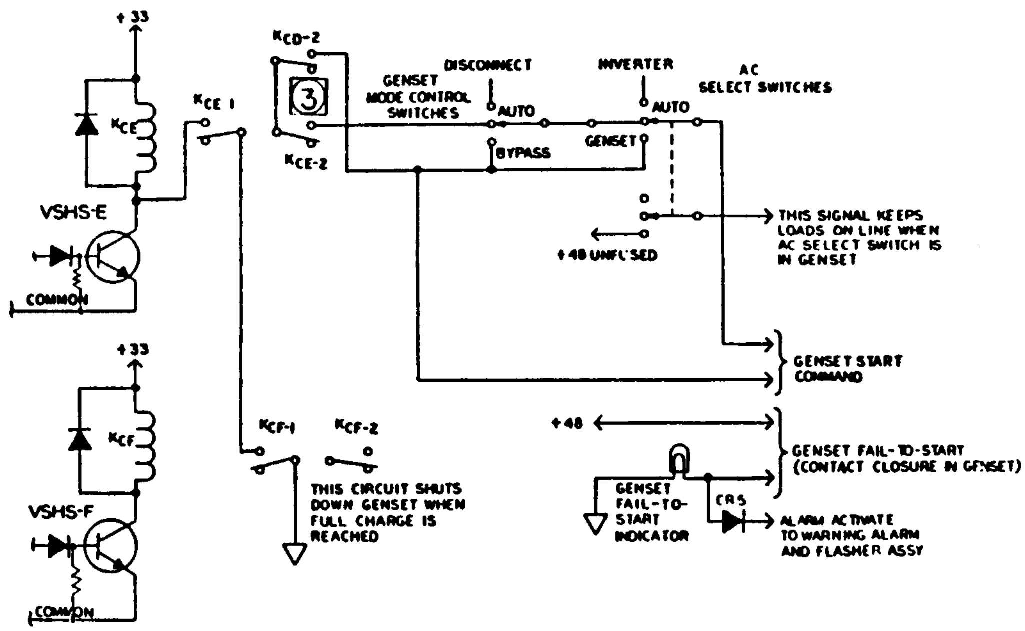


Figure 2.7-6. GENSET Start and End of Charge Circuit

The GENSET charge cycle starts when the battery discharges to 46.8 VDC. The battery will also accept current from PV source circuits if the sun is shining. If the GENSET shutdown voltage is too high, the GENSET continues to run even if PV source circuit power is available. Failure of the shutdown circuit can result in idling of the generator, materially degrading GENSET performance, and leads to fouled jets and unwanted depositions in the combustion chambers. Problems in the shut-down circuits must be solved immediately! Table 2-7 summarizes the end-of-charge control states. Figure 2.7-6 is a simplified schematic of this function.

2.7.8 DC Ground Fault Protection and Crowbarring

Figure 2.7-7 is a functional schematic of the DC ground fault protection circuits and the crowbar functions. The ground fault detection relay is K_{GFS}. When a positive ground return current occurs in excess of 12 MADC from earth to neutral, K_{GFS} closes. This indicates that a conduction path, possibly through a person, has been established from a positive source circuit voltage point through ground and the neutral return.

The crowbar function is tested by applying an equivilant current through the crowbar test switch. The sensitivity of the ground fault sense circuits may be adjusted by changing the setting of the potentiometer R_S.

Table 2-7. End-of-Charge Truth Table

Control Point (or function)	Control Mode and Status		
	During Charging Cycle	At/During ON-OFF Transition	GENSET OFF Cycle
Battery Voltage	Less than 55 VDC	More than 55 VDC	More than 46.8 VDC but below 55 VDC
Comp F Input (Pos.)	Low	High	High or Low; a function of PV input
Comp F Output	High	Low	High or Low; a function of PV input
Transistor	On	To Off	Open/Close (Same as above)
KCF Coil Status	Energized	De-energized	
KCF-1 NO State *	Closed	Closed	
KCF-1 NC State **	Open	Open	
KCF-2 NO State *	Closed	Open	
KCF-2 NC State **	Open	Closed	
GENSET Start Line Solenoid	Open	Momentary	Open
GENSET Fuel Pump	On	Off	Off

* (NO) Normally Open
** (NC) Normally Closed

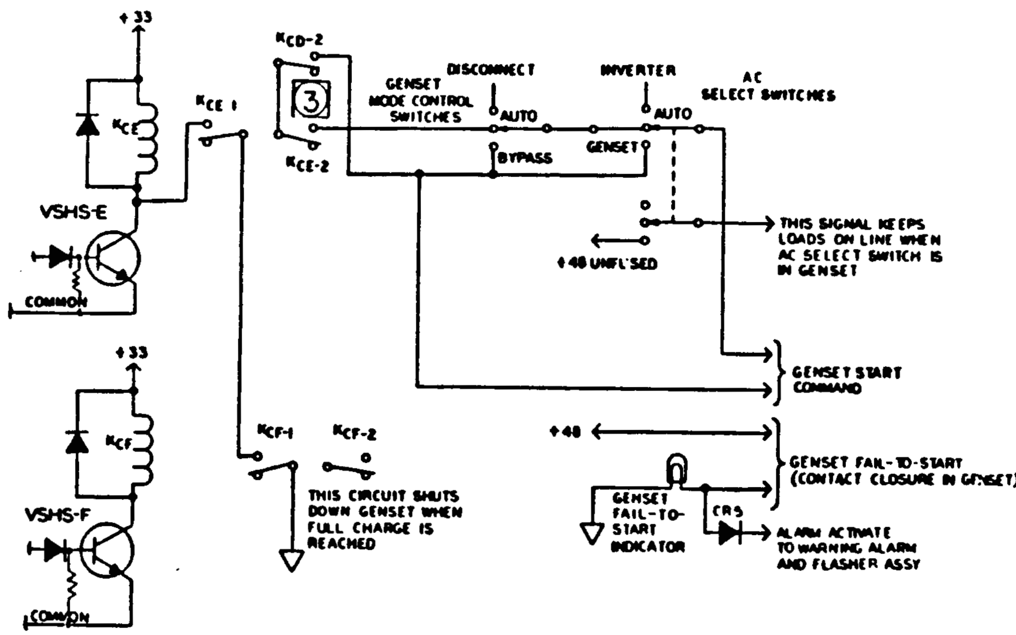


Figure 2.7-6. GENSET Start and End-of-Charge; Simplified Schematic

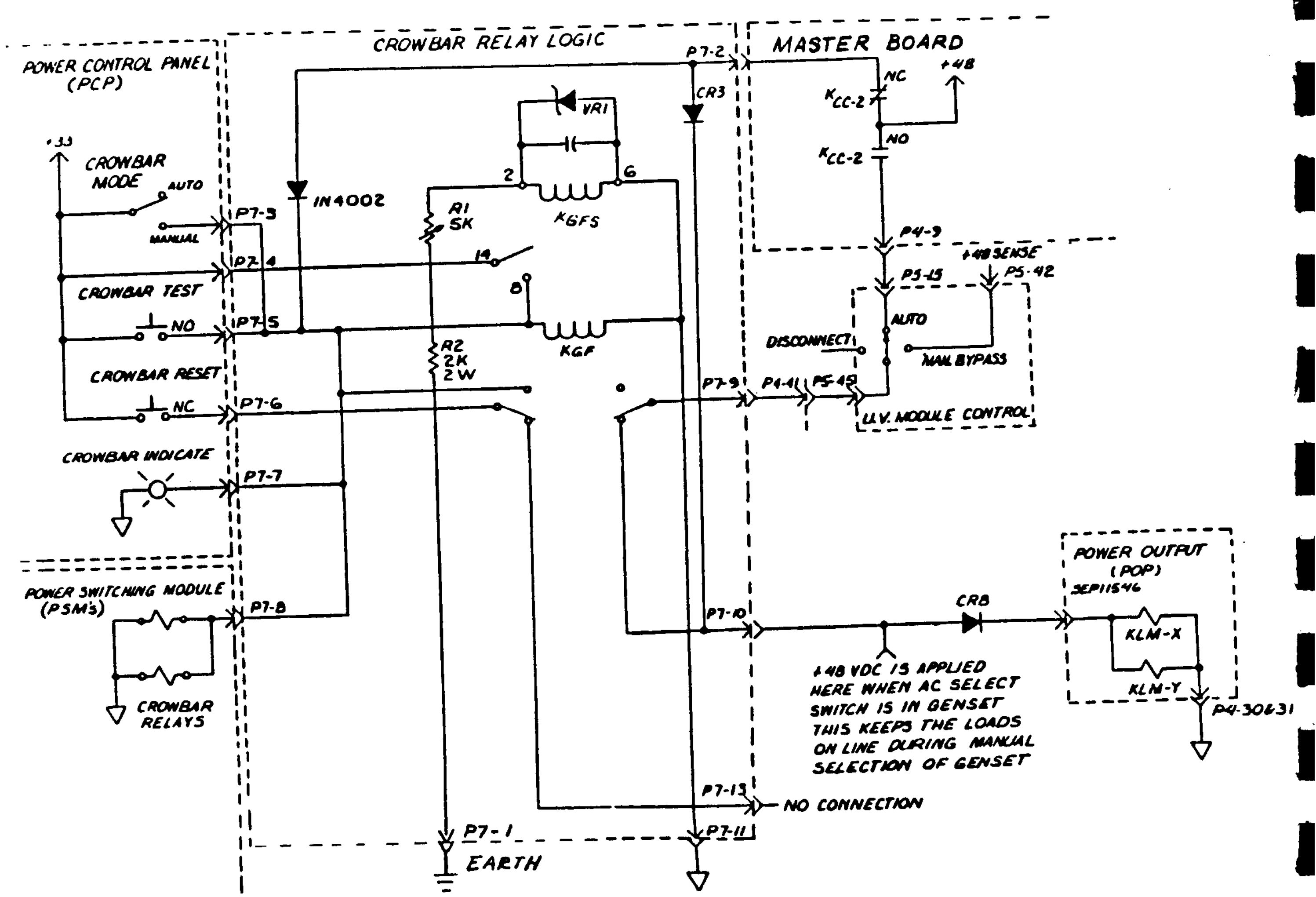


Figure 2.7-7. Ground Fault Crowbar Logic

3.0 SYSTEM DESIGN DESCRIPTION

Figure 3.0-1 identifies major elements of the power system. The energy producers are the PV array field and the GENSET. The PV array field is the preferred power source. The GENSET provides back-up or stand-by power; it is considered as the alternate source. This section describes the various functional subsystems and elements that generate, control, condition the system power, or store the energy produced.

3.1 PHOTOVOLTAIC POWER GENERATOR

The latitude of Wawatobi is approximately three degrees South. The long horizontal axis of the photovoltaic array field is sited E-W. The panels are inclined about twelve degrees north, principally to ensure adequate water run-off. The northerly tilt also modestly increases the ambient insolation in the months immediately preceeding and following the winter solstice in the southern hemisphere, but at the expense of their summertime levels.

The PV array field wiring topology is depicted in Figure 3.1-1. Prefabricated jumper cables are used to interconnect the PV modules in the requisite series strings that form the basic source circuits. These outputs are routed in buried conduit to the power controller, where they are summed in each of two identical power control channels. The array output comprises the sum of these channels. Figure 3.1-2 depict the standard connector assemblies. The upper plug receptacle pair is used in the panel jumpers. The hybrid female receptacle is integral with the panel assembly. The lower "SUPERCON" connection system is used for terminating the battery conductors.

The PV Array Field consists of 24 PV modules, each 2 ft by 4 ft which house the solar cells. Four PV modules are wired in series to produce 60 VDC. This is called a source circuit; six source circuits, wired in parallel, generate the system power, about 1584 watts. The six source circuits are divided into two groups of three source circuits to form two power generating Channels, A and B, each producing one half the PV power. These two channels are controlled by circuit breakers mounted on the Power Switching Module in the Power Controller.

Four PV modules are physically assembled together to form a panel. Each PV panel in the PV Array Field consists of two vertical side support channel members 10 ft. (3.0 m) long, joined by the horizontally mounted PV modules. The channel members are 3 inches (75 mm) deep and have 2 inch (50 mm) flanges. Adjacent panels share common front mounting posts and rear support legs.

The panel area is 4 ft (1.21 m) by 8 ft (2.42 m) consisting of 4 PV modules. The 10 ft (3.0 m) channel members provide the additional length needed for module ground clearance. The channels are made from galvanized sheet steel.

3.2 MODULES AND PANELS

The output power of a PV cell is proportional to the intensity of the incident solar radiation. The PV cells are electrically wired together and physically encapsulated into modules wired and grouped together to form the assembled PV array, the power generator. The output voltages add when modules are connected in series. Within dielectric limits, it is possible to produce almost any

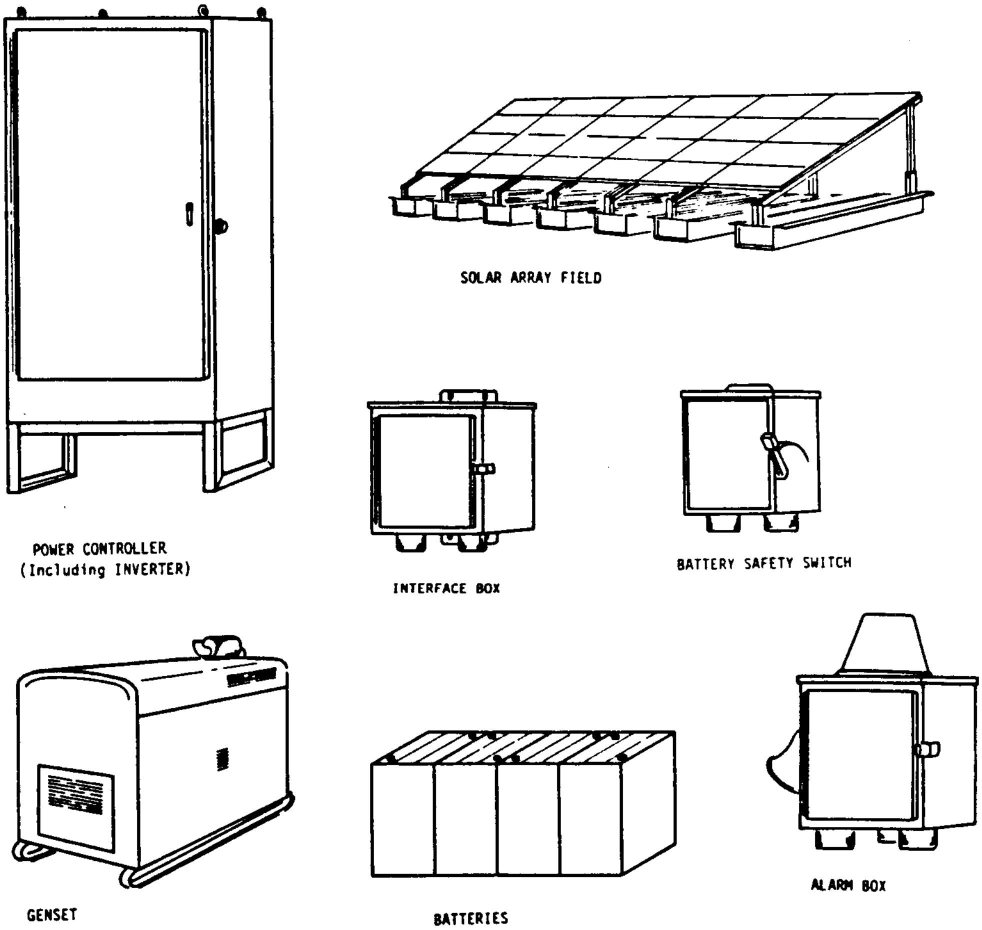


Figure 3.0-1 PV Power Systems Components

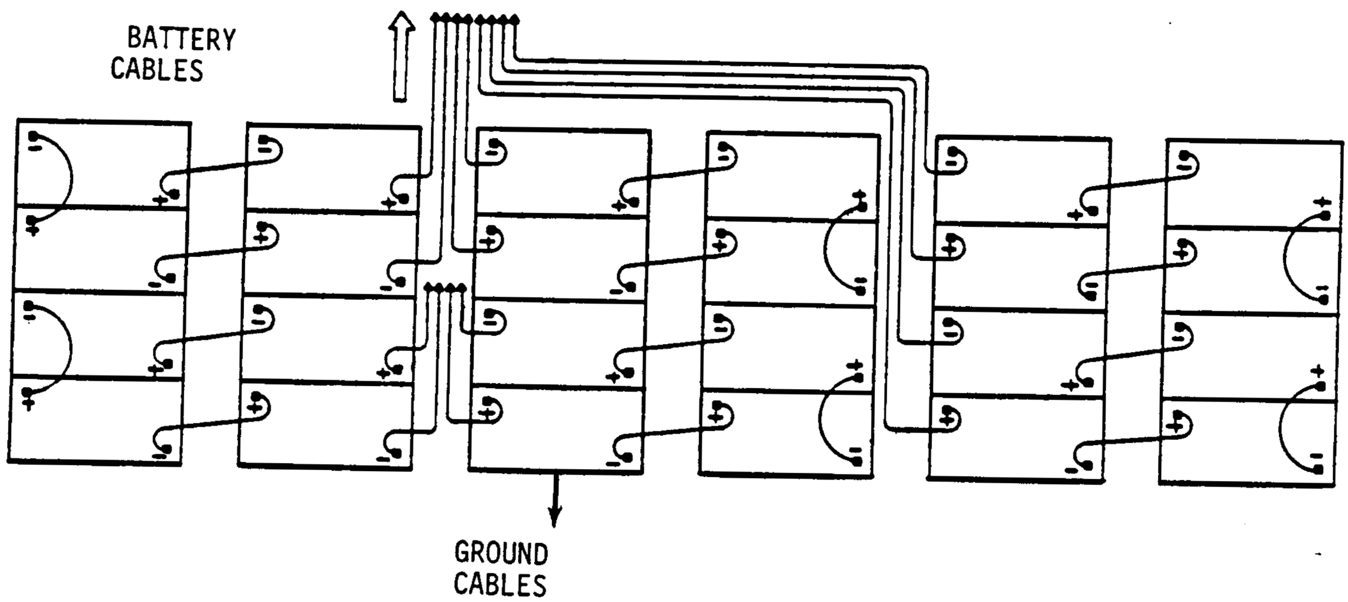
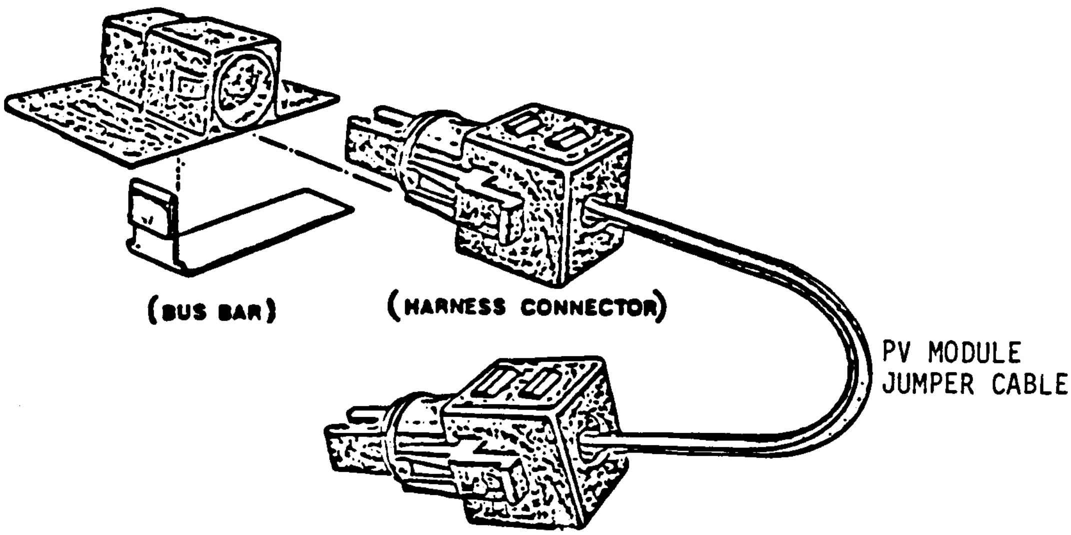
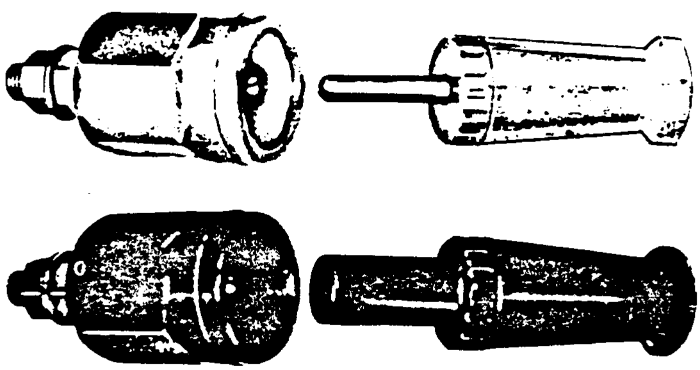


Figure 3.1-1 PV Array Field Wiring Configuration



"SOLARLOK" PV MODULE CONNECTORS



"SUPERCON" BATTERY CABLE CONNECTORS

Figure 3.1-2 Connector Assemblies

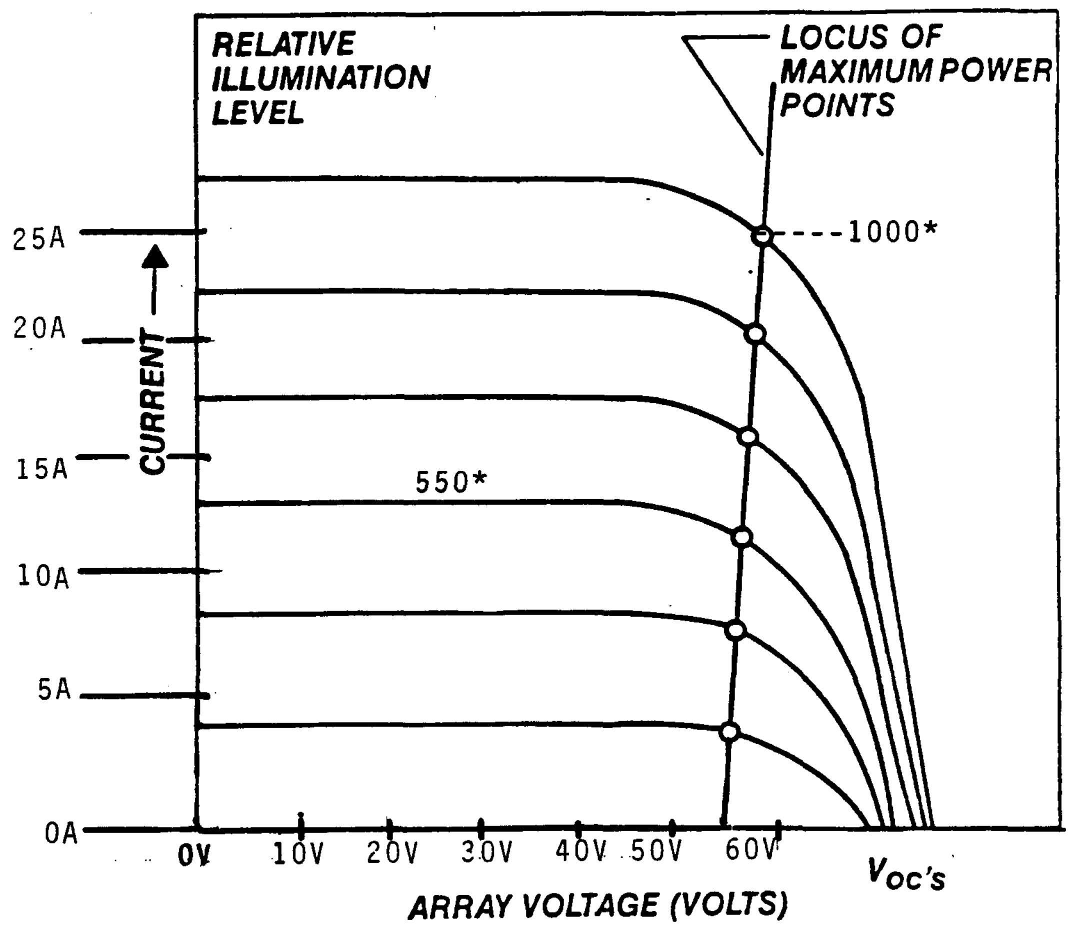
combination of voltage and current output by selective series/parallel interconnect topologies. The photovoltaic cell is a quasi-constant current device. The voltampere characteristics of the assembled field, based upon those of individual modules, is approximated in Figure 3.2-1. Refering to this figure, it may be seen that the open circuit voltage is not inordinately greater than the voltage at maximum power. The design intent is to operate the photovoltaic array as close to the maximum power point as possible. Operation at the MPOP (MAXIMUM POWER OPERATING POINT) for all ambient insolation levels minimizes the cost of the array for any required power level. The wide variation of battery bus voltage with on-charge voltage and battery state-of-charge, in general, precludes continuous operation at MPOP.

PV modules from Soltec International Inc. of Hawthorne, CA were selected for this project. These modules are rated at 15.6 VDC and 4.23 ADC at 28 degrees Celsius when exposed to solar insolation of 1000 watts per square meter. The basic source circuit is a four module series string, rated 63 volts peak at 4.23 amps (peak). This voltage is compatible with the efficient charging of a 24 cell, (48 VDC nominal) Lead Calcium battery employing 1.300 specific gravity electrolyte. (nominal cell potential of two volts). Sizing calculations indicated that a PV array output of approximately 1600 watts (peak) would be developed from six paralled strings of the four series wired modules. A nominal output current of 25 ADC would be thus available for recharging the battery and/or supporting the station/classroom load. These levels again would be available at a solar insolation of 1000 watts per square meter, and at a cell junction temperature of 28 degrees Celsius. At the expected 48 degrees cell ambient, the field would generate approximately 1400 watts peak.

Referring again to Figure 3.2-1 the I-V characteristics vary linearly with changing cell irradiance or illumination level. The current and voltage characteristics are both temperature dependent. The short-circuit current of the array is directly proportional to the irradiance level, and the open circuit voltage is a linear inverse function of the cell temperature. The latter decreases about 0.5% of its 25 degree C value for each 1 degree of increasing cell temperature. This sensitivity to ambient cell temperature dictate that design means be sought to keep the array as cool and as well ventilated as possible, consistant with maximizing the annual incident energy available for conversion. It may be expected that the array at Wawatobi would generate maximum power on a cool bright spring or autumn day, shortly after a cooling rainstorm had passed. Adjacent clouds, not obscuring direct insolation falling upon the array, may enhance the incident flux. Irradiance in the range of 1100 watts per square meter might well be observed.

3.3 PV FIELD ARRAY STRUCTURES

The array structure is a simple, above-ground assembly composed of foundation tubs, upright supports and cross straps. The tubs are filled with ballast material, such as rocks or earth, obtained from the installation site. The system batteries are mounted on the top of the tubs to add additional ballast weight to the structure. Details may be seen in Figure 3.3-1 following, a photograph of the Wawatobi Array field Installation. System transportability, or ease of relocation was given as one of the design guidance criteria. The design is compatible with this requirement. In routine installation all



(*) SOLAR INSOLATION AT SITE IN WALLS PER METER SQUARED

Figure 3.2-1. I-V Characteristics for Various Levels of Array Illumination

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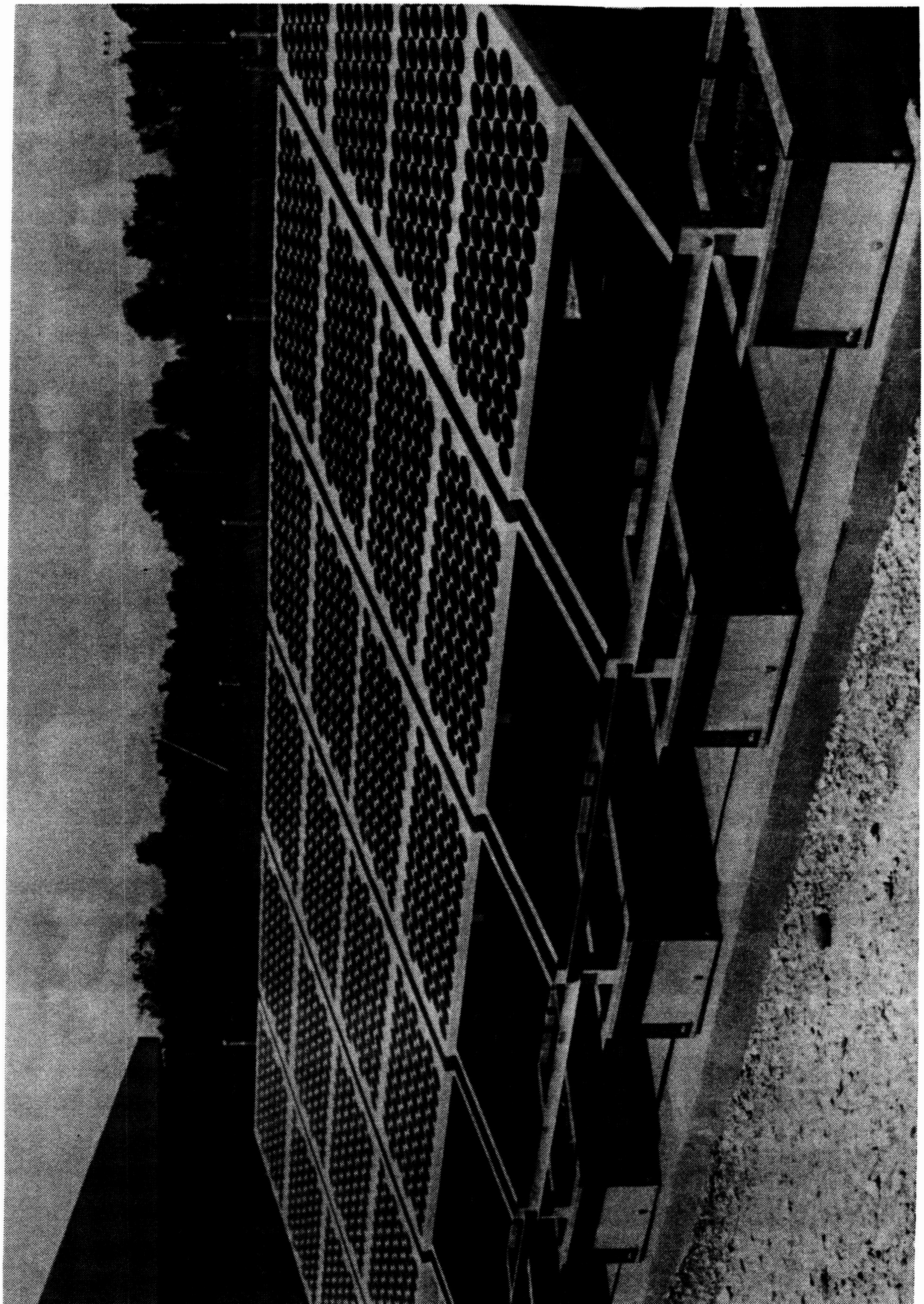

Figure 3.3-1 Array Field Installation Details

hardware is completely recoverable since earth anchors and sub-surface foundations are not used. It was known that the Wawatobi installation would be used for both training and feasibility demonstration. Since the system would be essentially "showcased" it was decided to install the structures on a uniform concrete pad, and at the same time retain the tubs to demonstrate portability.

3.4 POWER CONTROLLER

The power controller depicted in Figures 3.4-1 and 3.4-2 houses a power switching module, power control panel, power output panel, inverter, instrument panel, and battery charger. All major circuits within the power system pass through the power controller.

Metallic oxide varistors (MOVs) are used at the input/output terminals of the power controller to limit momentary surge voltages.

A ground wire, consisting of galvanized wire, is buried in cable trench about 18 inch (450 mm) deep. These wires are secured to one point on each part of the perimeter fence, at both ends of each row of PV panels, and to the power controller. A solid low resistance ground from the power controller to outlet boxes assures electrical safety. The ground wires are connected to the water table with ground rods.

3.4.1 Power Switching Module (PSM)

The power switching module shown in Figures 3.4-3 has two channels; each controls 50 percent of the array power. The six source circuit inputs are equally divided and routed to channel A and B for control prior to merging on the battery bus. The main control elements on the power control circuitry of each PSM channel are:

a. The input circuit breaker.

b. The control contactor.

c. An array shorting or crowbar contactor. Power blocking diodes and surge arrestors are also included.

Referring to Figure 3.4-2, the PSM front panel is located just below the uppermost one, the Instrumentation Panel.

3.4.2 Power Control Panel (PCP)

The power control panels contains the following:

a. System status displays and indicators.

b. A zero centered battery current (bipolar) meter.

c. A ground fault relay.

d. A master printed circuit card termed the control "motherboard".

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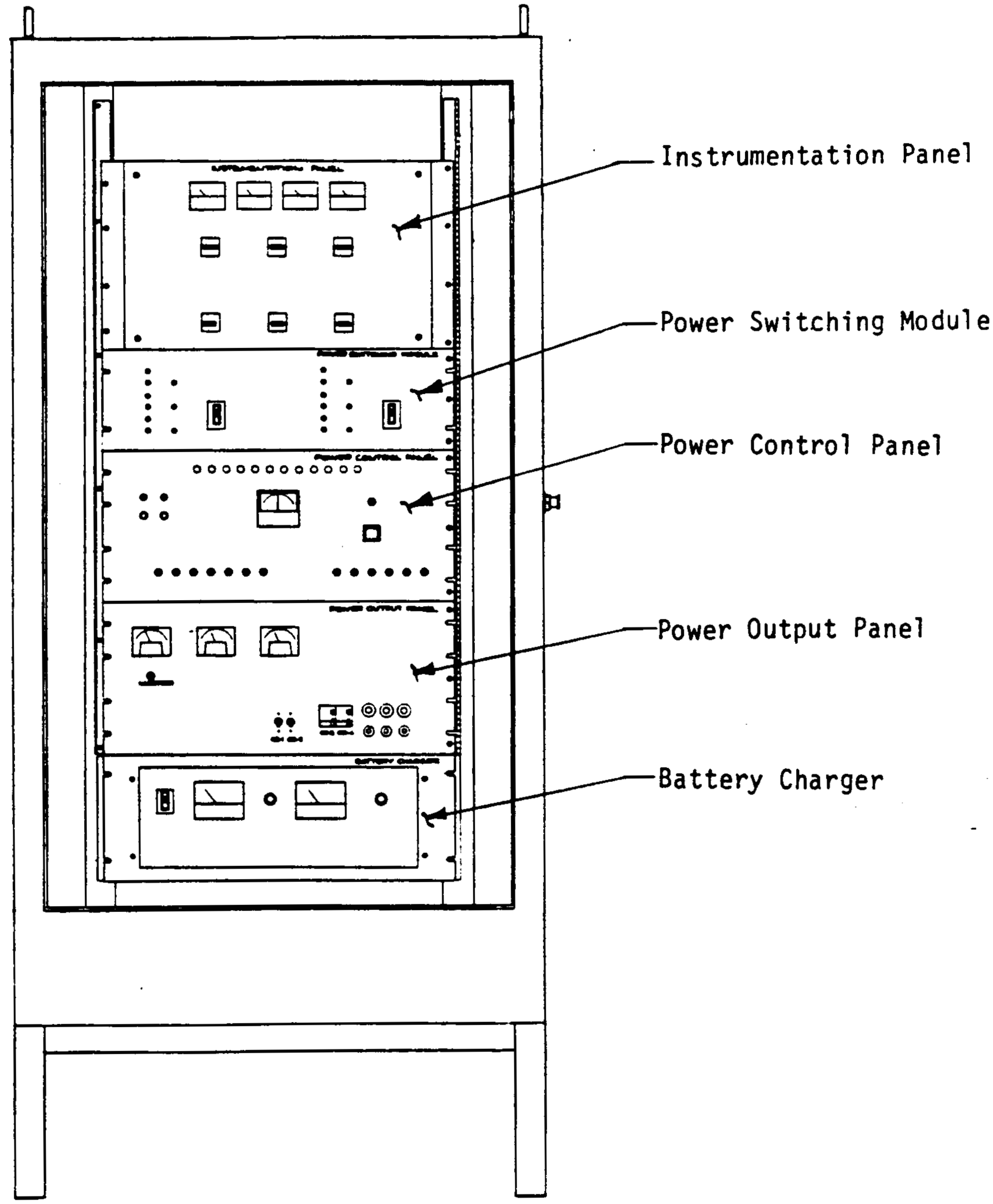


Figure 3.4-1. Power Controller

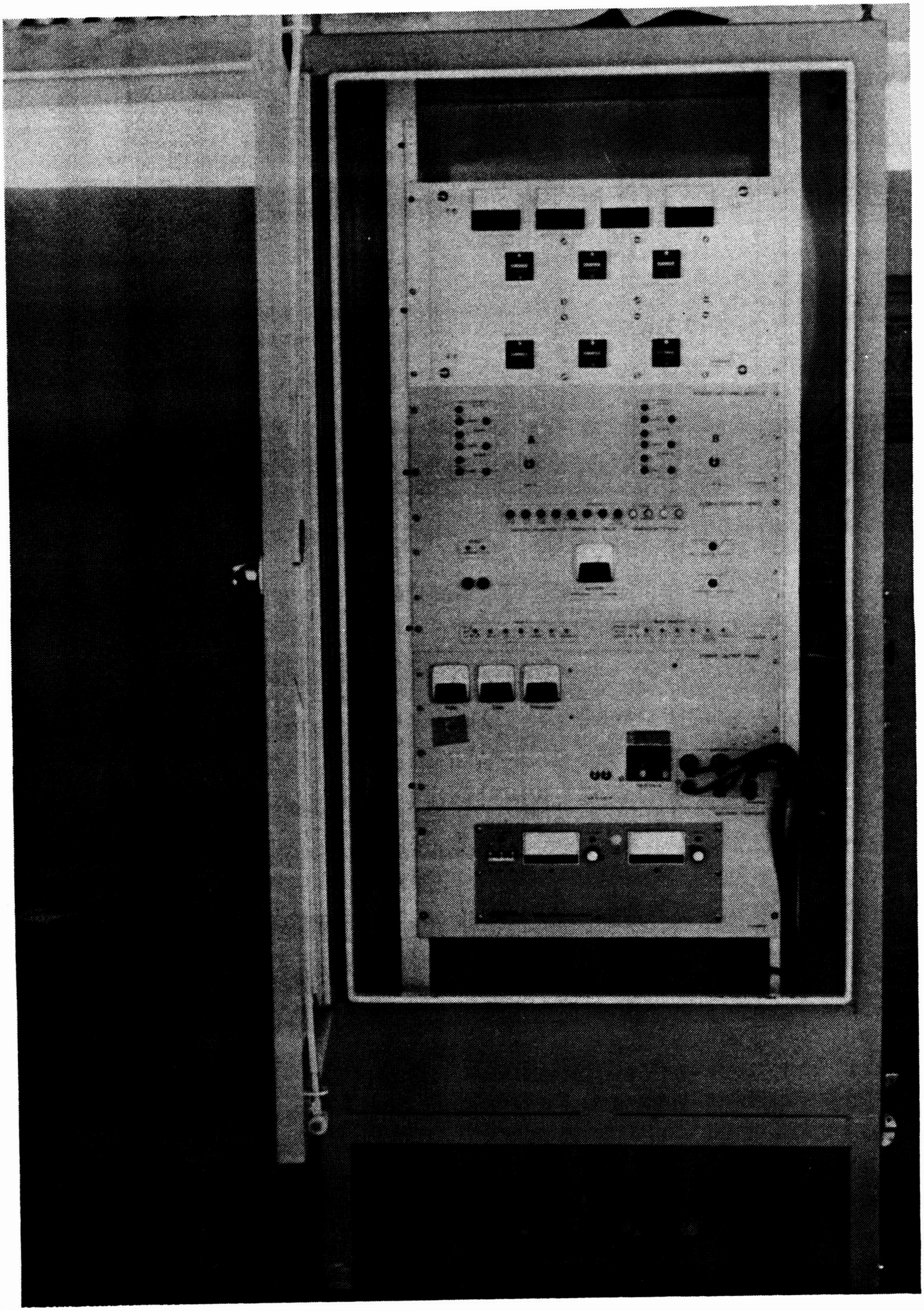
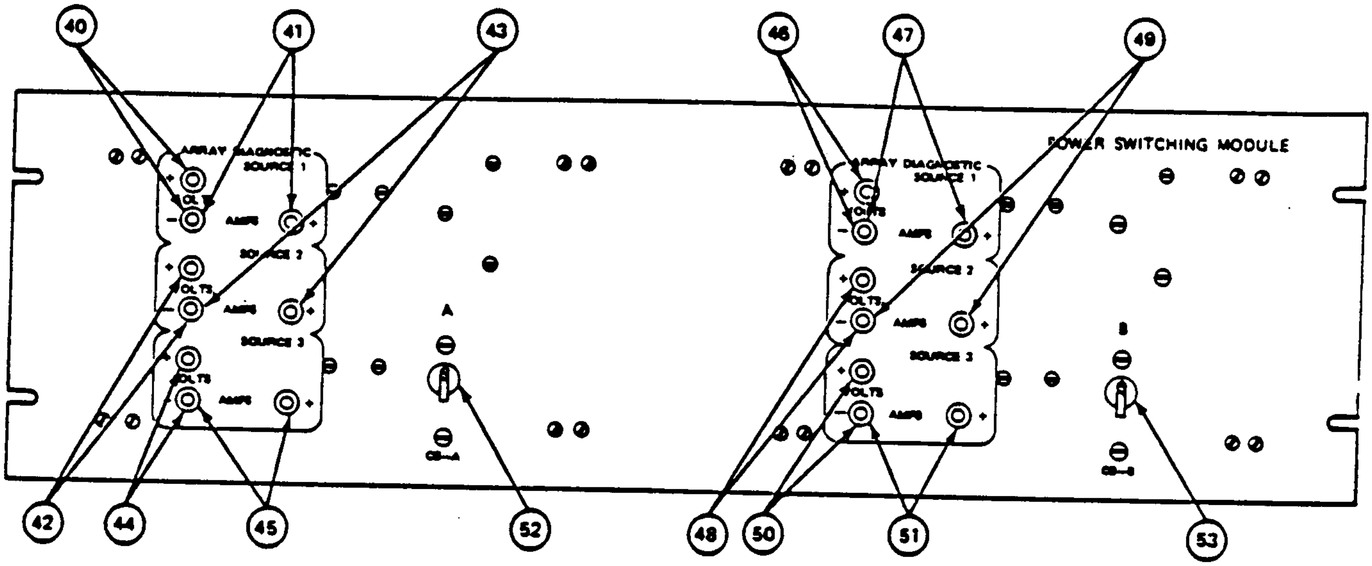


Figure 3.4-2. Photo of Power Controller



LEGEND:

NUMBER	ITEM
40.	VOLTAGE MEASUREMENT, 0-100VDC SCALE
41.	CURRENT MEASUREMENT, 0-10 ADC SCALE
42.	VOLTAGE MEASUREMENT, 0-100 VDC SCALE
43.	CURRENT MEASUREMENT, 0-10 ADC SCALE
44.	VOLTAGE MEASUREMENT, 0-100 VDC SCALE
45.	CURRENT MEASUREMENT, 0-10 ADC SCALE
46.	VOLTAGE MEASUREMENT, 0-100 VDC SCALE

NUMBER	ITEM
47.	CURRENT MEASUREMENT, 0-10 ADC SCALE
48.	VOLTAGE MEASUREMENT, 0-100 VDC SCALE
49.	CURRENT MEASUREMENT, 0-10 ADC SCALE
50.	VOLTAGE MEASUREMENT, 0-100 VDC SCALE
51.	CURRENT MEASUREMENT, 0-10 ADC SCALE
52.	CIRCUIT BREAKER CHANNEL A
53.	CIRCUIT BREAKER CHANNEL B

Figure 3.4-3. Power Switching Modules

The PCP is depicted in Figure 3.4-4; referring to Figure 3.4-2, it is located between the PSM and the Power Output panel.

3.4.3 Power Output Panel (POP)

The power output panel controls the flow of all power to the satellite earth station and classroom loads. The batteries are connected to the DC bus via polarized supercon connectors. The DC array power from the PSM is fed to the DC bus. The isolating circuit breakers for the DC output power and the inverter input are on the panel. AC power from either the Inverter or the GENSET is selected on this panel. The AC power is monitored by the three panel meters (VRMS, IRMS, and FREQUENCY). The AC circuit breakers for the classroom loads and the maintenance power are also located on the panel, (refer to Figures 3.4-7 and 3.4-2).

The continuous carry current and fault circuit current ratings of the DC circuit breakers are matched with the battery fuses, Each mercury displacement contactor and circuit breaker pair are series connected. Both are dedicated to a particular distribution feeder. The load buses, as well as the positive (+) and negative (-) battery connections, use the supercon connector system. As a safety feature, individual plug/receptacle pairs are non-interchangeable.

3.4.4 800 Watt Inverter

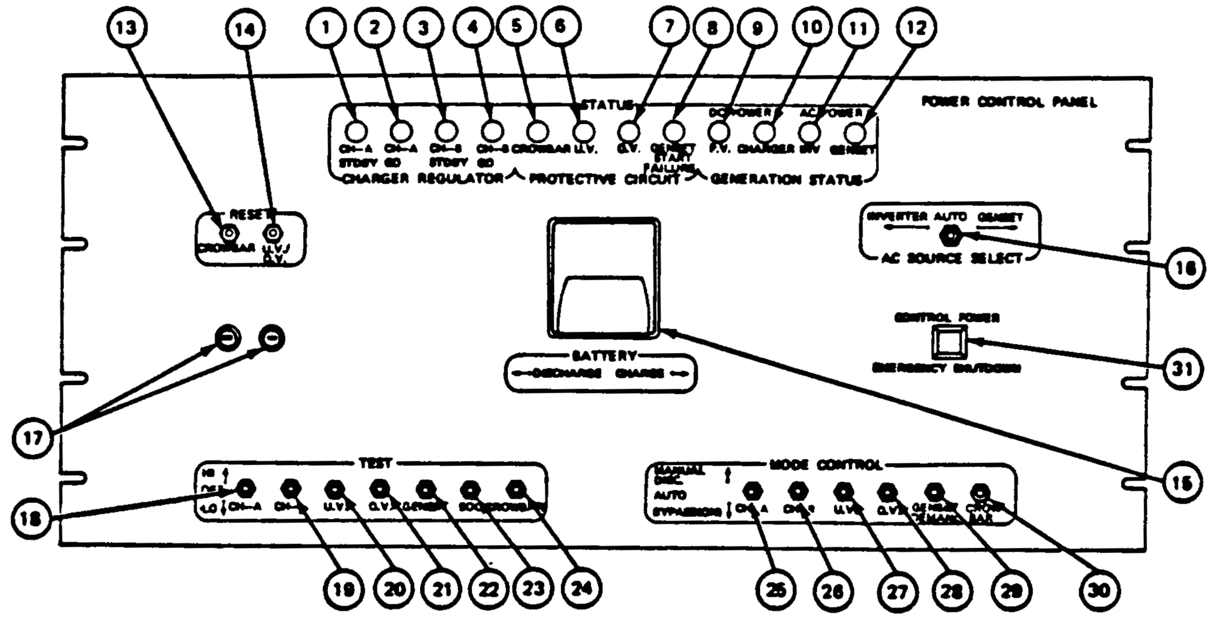
The DC/AC inverter converts 48 V dc into 240 Vac 50 HZ, single phase as a means of continuously powering the classroom and Earth Station AC loads from the renewable PV energy source. Figure 3.4-6 shows the outline and general arrangement of this module.

The inverter is housed in a steel-wrap around enclosure; it is mounted on an interior wall of the power controller compartment. The switching transistors are mounted upon a massive finned heat sink that also serves as the baseplate for electronic assembly. The inverter envelope is depicted in Figure 3.4-6.

The inverter is of the synthesized sinewave type, featuring accurate voltage and frequency regulation under all conditions of line, load, and ambient temperature. Table 3.4-6 summarizes its physical and functional characteristics.

3.4.5 Instrument Panel

The Instrumentation Panel is shown in Figure 3.4-7. It consists of selected voltmeters shunt-driven ammeters, and amp-hour meter counters. These meters and counters provide a visual display of the individual status of the power sources, the system battery, and the loads. The current meters are driven by very low resistance current viewing resistors or shunts; the attendant voltage drops in the supply buses are in the millivolt range. The counters keep a coulombic record of the total current flowing out of the arrays or battery charger, in and out of the battery, or into the earth station and classroom loads. These current integrals are displayed on totalizing counters of the Veeder-Root type. The power controller photograph, Figure 3.4-2 shows the instrumentation panel.



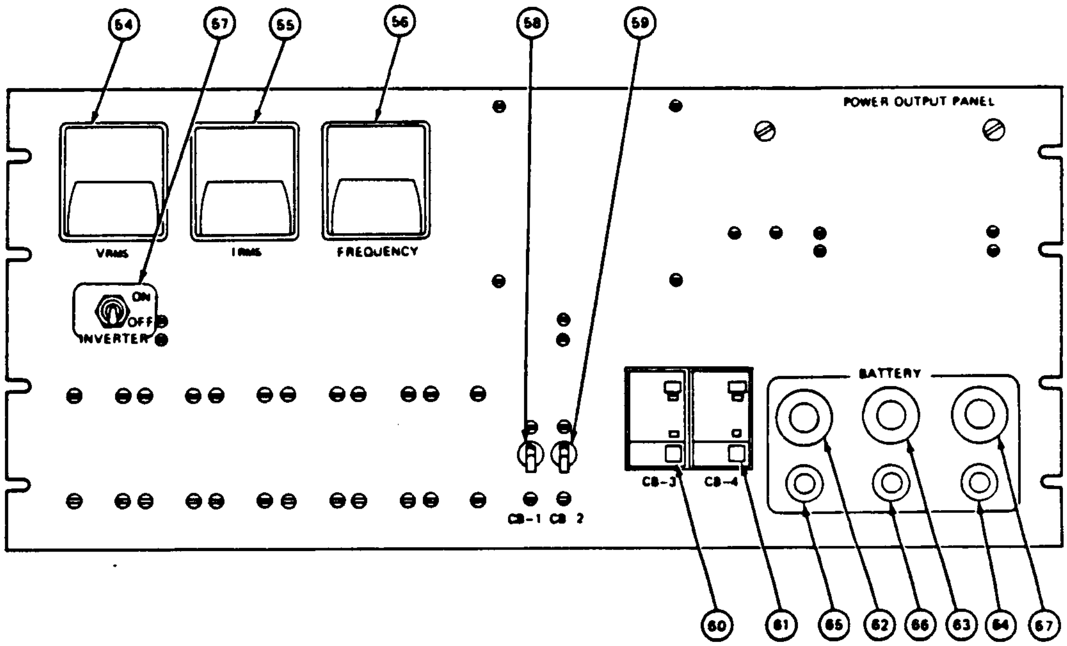
LEGEND:

NUMBER	ITEM
1.	STATUS LAMP: PV CHARGER CHANNEL A-STANDBY
2.	STATUS LAMP: PV CHARGER CHANNEL A-GO
3.	STATUS LAMP: PV CHARGER CHANNEL B-STANDBY
4.	STATUS LAMP: PV CHARGER CHANNEL B-GO
5.	CROWBAR CIRCUITS ACTIVATED INDICATOR
6.	UNDERVOLTAGE STATUS INDICATOR
7.	OVERVOLTAGE STATUS INDICATOR
8.	GENSET FAIL-TO-START INDICATOR
9.	PV ARRAY DC POWER INDICATOR
10.	AC/DC CHARGER DC INDICATOR
11.	AC POWER INDICATOR
12.	GENSET AC POWER INDICATOR
13.	RESET PUSHBUTTON (CROWBAR)
14.	RESET PUSHBUTTON (UNDERVOLTAGE/OVERVOLTAGE TRIP)
15.	BATTERY CURRENT METER (CENTER 0)
16.	AC SOURCE SELECTION SWITCH

NUMBER	ITEM
17.	CONTROL POWER FUSES
18.	CHANNEL A TEST
19.	CHANNEL B TEST
20.	UNDERVOLTAGE TEST
21.	OVERVOLTAGE TEST
22.	GENSET STARTING TEST
23.	GENSET END-OF-CHARGE
24.	CROWBAR TEST
25.	CHANNEL A MODE SELECT
26.	CHANNEL B MODE SELECT
27.	UNDERVOLTAGE PROTECTIVE MODE SELECT
28.	OVERVOLTAGE PROTECTIVE MODE SELECT
29.	GENSET DEMAND POWER SELECT
30.	CROWBAR MODE CONTROL
31.	CONTROL POWER EMERGENCY SHUTDOWN

SELECT:
MANUAL DISC
AUTO
BYPASS (ON)

FICURE 3.4-4 THE POWER CONTROL PANEL



LEGEND:

NUMBER	ITEM	NUMBER	ITEM
54.	AC BUS VOLTAGE, 230V VAC NOMINAL	61.	GROUND FAULT INTERRUPTOR
55.	TOTAL AC OUTPUT AMPERS	62.	(+) BATTERY STRING #1
56.	FREQUENCY OF AC SOURCE ON BUS	63.	(+) BATTERY STRING #2
57.	INVERTER ON/OFF SWITCH	64.	(+) BATTERY STRING #3
58.	DC POWER TO EARTH STATION DC BUS	65.	(-) COMMON BATTERY STRING #1
59.	DC POWER TO INVERTER	66.	(-) COMMON BATTERY STRING #2
60.	GROUND FAULT INTERRUPTOR	67.	(-) COMMON BATTERY STRING #3

FIGURE 3.4-5 THE POWER OUTPUT PANEL

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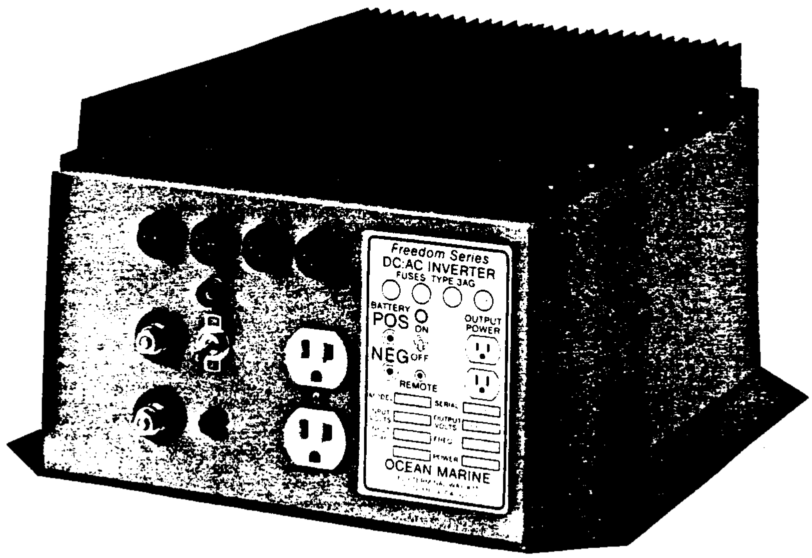
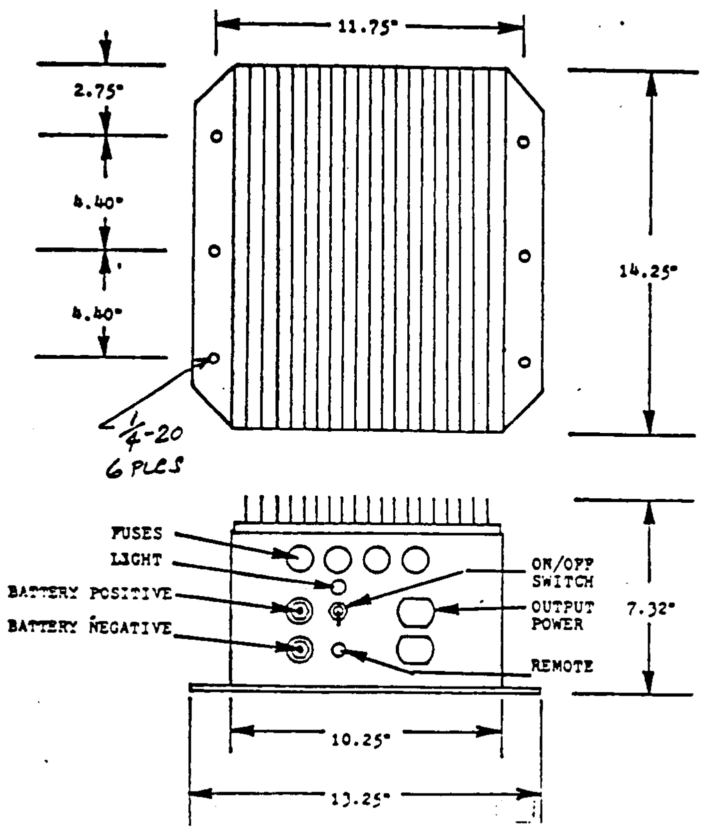
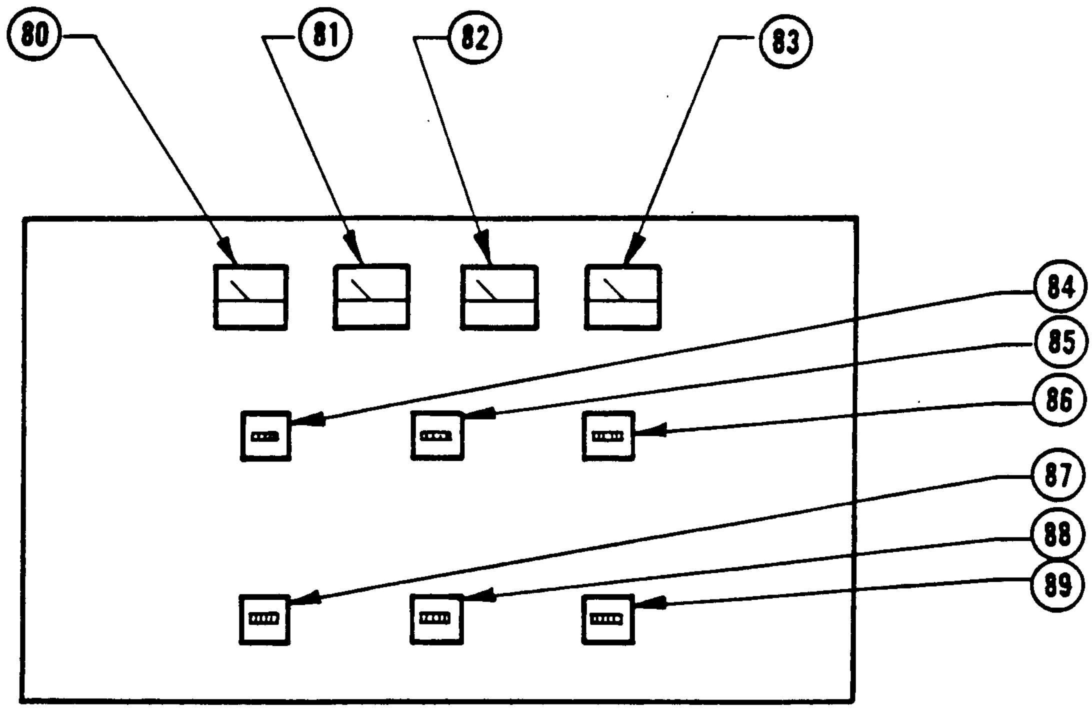
OUTLINE DRAWING,
SHOWING CONTIGUOUS
HEAT SINK ON TOP
SURFACE





INSTALLATION DRAWING AND
MOUNTING DIMENSIONS FOR
OCEAN MARINE INVERTER

FIGURE 3.4-6 OUTLINE DRAWING OF THE 800 WATT SYNTHESIZED SINEWAVE OCEAN MARINE SOLID-STATE INVERTER



LEGEND:

NUMBER	ITEM	NUMBER	ITEM
80.	PV GENERATED AMPS	85.	BATTER CHARGE A-H COUNTER
81.	BATTERY CHARGER AMPS	86.	BATTER DISCHARGE A-H COUNTER
82.	DC LOAD AMPS	87.	CHARGER OUTPUT A-H COUNTER
83.	BATTERY VOLTS	88.	INVERTER INPUT A-H COUNTER
84.	PV ARRAY A-H COUNTER	89.	EARTH STATION A-H COUNTER

FIGURE 3.4-7 DEPICTION OF INSTRUMENTATION PANEL

TABLE 3.4-6 SUMMARY PERFORMANCE AND DESIGN SPECIFICATIONS FOR THE "FREEDOM/OCEAN MARINE INVERTER.

ELECTRICAL SPECIFICATIONS:

Output Voltage:	240vac, 50 Hz., Single Phase
Output Power:	2.4 KW/2.4KVA at Unity Power Factor
Voltage Regulation:	Plus/Minus 2%, no-load to full load at battery bus voltages 48VDC-to 64VDC.
Frequency Accurracy:	50 Hz. plus/minus 0.1%
Waveform:	Step approximated sinewave, four steps.
Battery Current:	Proportional to load
Standby Current:	Approximately 0.2% of rated current with load demand circuit activated.
Efficiency:	Approximately 90% at full load
Overload Protection:	Automatic Current Limiting
Undervoltage Cutout:	Unit shuts down when bus voltage falls below 40 volts

Mechanical/Physical Characteristics

Cooling:	Natural Air Flow
Size:	10" x 14" x, 7-1/2"
Weight:	40 lbs.
Mounting:	Any position; vertical preferred for cooling
Connection:	1/4" Brass studs

3.4.6 Battery Charger

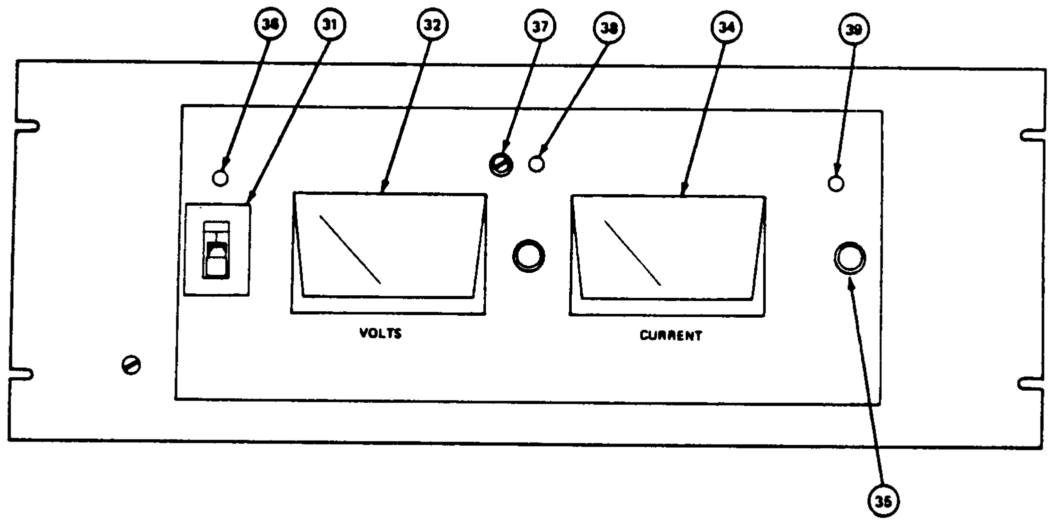
The battery charger is an industrial quality Silicon Controlled Rectifier Power Supply produced by Electronic Measurements Inc. It features precise electronic voltage regulation and dynamic current limiting. Its maximum charging voltage is 60 Vdc; the current limiter may be set to pass charging currents as high as 30 amperes.

The battery charger will charge the batteries and simultaneously support the power systems load. Precise voltage regulation over a temperature range of 0°C (32°F) to 50°C (122°F) is provided. The device is depicted in Figure 3.4-8 following, and in Figure 3.4-2 preceeding.

3.5 ENERGY STORAGE (BATTERY) SUBSYSTEM

3.5.1 Battery Complement

The PV energy storage or battery subsystems consists of three series strings of C and D 3KCPS5A battery modules paralleled on the DC bus. Each C& D battery module contains three series lead-acid rated 225 Ah, (8 hr rate). There are eight battery modules in each series string or a total of 24 series cells. Under the PV float cycle charging regime, backed up by periodic on-demand replenishment by the GENSET/CHARGER, the batteries should last at least seven years. The batteries are installed under the PV arrays on fiberglass battery platforms that are bolted across the ballasted planter's top flanges. The batteries serve as ballast. The panel shading helps keep the batteries cool.



LEGEND:

NUMBER	ITEM
31A.	ON/OFF RESETTABLE CIRCUIT BREAKER
32.	VOLTMETER (OUTPUT READING:0-ADC)
33.	VOLTAGE ADJUST KNOB
34.	AMMETER (OUTPUT READING:0-ADC)
35.	CURRENT LIMIT ADJUSTMENT POTENTIOMETER
36.	POWER ON LIGHT (RED)
37.	CIRCUIT BREAKER
38.	VOLTAGE LIMIT INDICATOR
39.	CURRENT LIMIT INDICATOR

FIGURE 3.4-8 THE GENSET POWERED BATTERY CHARGER

The battery terminals are protected by removable plastic safety covers. These covers also provide protection from danger due to contact with dangerous voltages.

The battery cables are routed to the power controller via the battery safety switches which protect each string, as well as the end usage devices, from damaging currents.

Figure 3.5-1 is a photograph taken late in the installation phase. It shows the major system elements, including the array field, the structures, the controller, and the batteries. Since it is a rear view, considerable detail is evident on the safety switch installation, the conduit terminations, and the general battery topology. The alarm box may also be seen in the background, on the left upper corner of the protective enclosure.

Pertinent design and performance data concerning the selected C&D battery modules summarized in Table 3.5-1 following. Subsequent curves more fully characterize this particular lead-calcium cell. It should be noted that the stated voltage characteristics, given on a per cell basis, must be multiplied by 60X to yield the bus voltage. Similarly, the stated current/ampere-hour capacity must be multiplied by six to obtain the coulombic or current performance of the six paralleled string of which entire battery is comprised.

3.5.2 Battery Safety Switches

The battery switches contain battery fuses and a safety switch. The power system use three safety switches, one for each battery string. Each battery string contains eight batteries wired in series. This fused switchgear will clear the battery source circuits or permit rapid manual disconnect in the event of overcurrent and/or fault conditions on the system DC bus. In addition, one of the fuses in one of the battery safety switch boxes is placed in series with the emergency shutdown switch on the power controller. This switch allows the load to be separated from the source when it is pressed. The switchgear assembly is shown in Figure 3.5-10 following.

3.5.3 Battery Other Power Interfaces

Interface Box

The interface box consists of a terminal block and supporting hardware enclose in a metal box. This interface box connects 48 VDC from the batteries and 220 VAC from the inverter to the load. See Figure 3.5-9 following.

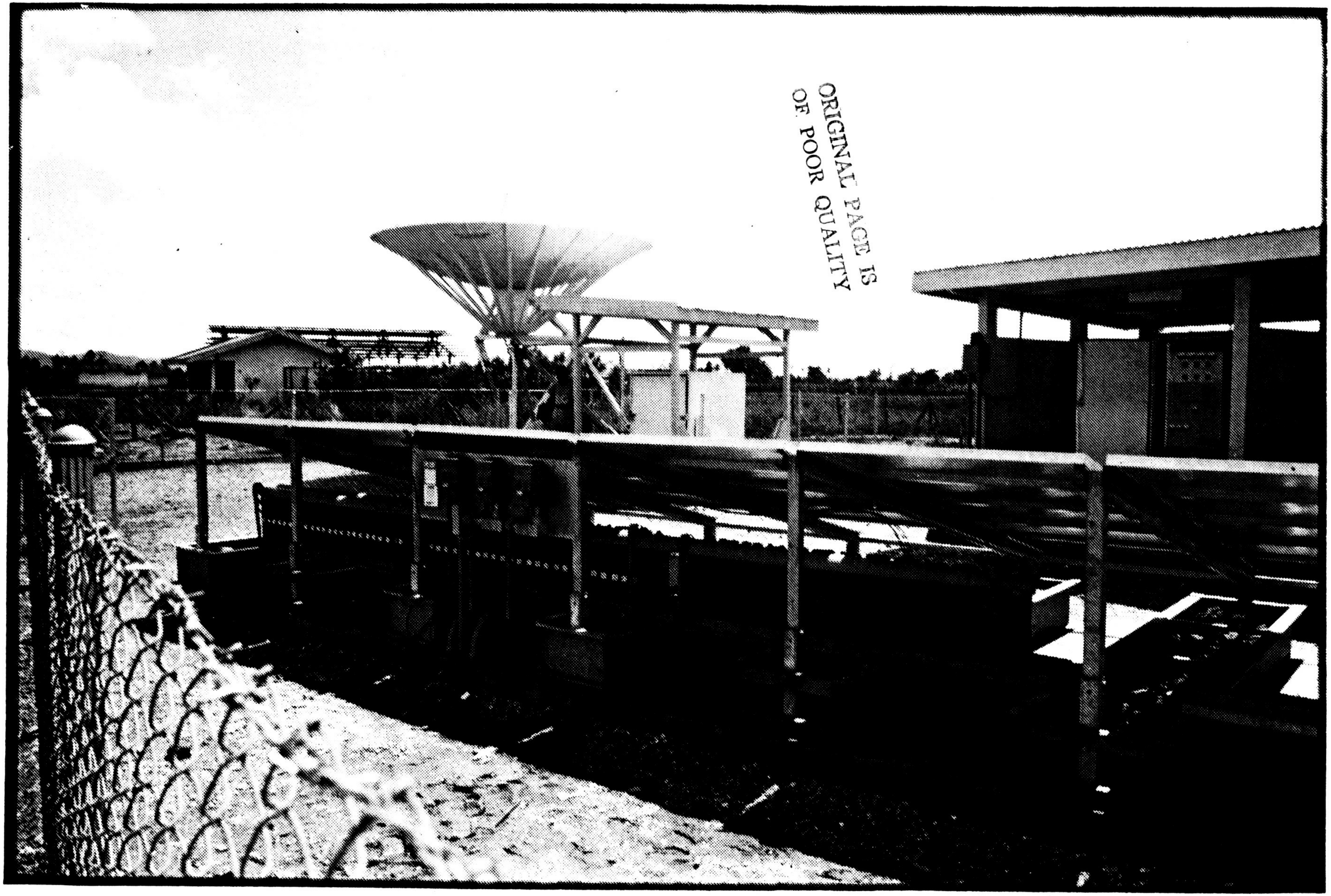


FIGURE 3.5-1 THE OVERALL PV POWER SYSTEM INSTALLATION, INCLUDING THE POWER CONTROLLER, THE BATTERY STRINGS, THE SAFETY SWITCHES AND CONDUIT TERMINATIONS, AND THE UNDERSIDE OF THE ARRAY

Table 3.5-1: Summary of Characteristics of the 3KCPSA--5 Battery Cell

FIGURE NUMBER	
3.5-2	CHARACTERISTICS OF C&D 3KCPSA-5 SHALLOW DISCHARGE BATTERY
3.5-3	APPROXIMATE OPEN CIRCUIT VOLTAGE OF A SHALLOW CYCLE C&D LEAD ACID BATTERY CELL AT VARIOUS DEPTHS-OF-DISCHARGE
3.5-4	RECOMMENDED FLOAT VOLTAGE RANGE FOR SHALLOW CYCLE TYPE C&D CELLS AT VARIOUS TEMPERATURES
3.5-5	APPROXIMATE AMP-HOUR RATED CAPACITY REMAINING AS A FUNCTION OF SPECIFIC GRAVITY (AT 77 DEGREES F)
3.5-6	AMPERE-HOUR CAPACITY OF A TYPICAL SHALLOW CYCLE C&D CELL FUNCTION OF ELECTROLYTE TEMPERATURE.
3.5-7	REPETITIVE CYCLE LIFE AS A FUNCTION OF THE DEPTH-OF-DISCHARGE
3.5-8	FREEZING POINT OF H_2SO_4 ELECTROLYTE CONCENTRATION

3.6 THE ONAN GENSET

The back-up fossil fuel fired power plant for subject system is Model 2.5 DJA-53CR air cooled diesel engine generator. It develops 2.5KW, 230 Vac at unity power factor, at a shaft speed of 1500 RPM. At 240 Vac output, it will supply approximately 10 amps of single phase load current.

Standard features and accessories include the following listing, taken from the ONAN DJA Technical Bulletin.

- Vibration Isolators
- Muffler
- Dual Fuel Filter
- Air Cleaner with reusable Polyrethane (oil wetted) Element
- Spin-on Full Flow Lube Oil Filter
- Low Oil Pressure Shutdown
- Oil Pressure Gauge
- Removable Lifting Eye
- Mounted Control Box with Charge Rate Ammeter, Start-Stop Switch, Preheat Switch (Manifold Heater and Glow Plug), Fuse DC Circuitry, Remote Control Terminals
- Battery Cables

SPEC[illegible]ONS [illegible] DCP[illegible] BATTERIES

[illegible]

Normal and Cold Climate Application Data
Average Annual Temperature less than 90°F (32°C)

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
DCPSA-1[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
DCPSA-15	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6.38	[illegible]	[illegible]	187	[illegible]	[illegible]	[illegible]	[illegible]
3KCPSA- 5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8.53	217	[illegible]	265	18.25	464	131.0	59.4
KCPSA- 7	337	384	389	[illegible]	400	3.62	92	10.44	265	18.25	464	58.0	26.3
KCPSA- 9	450	506	513	520	524	4.62	117	10.44	265	18.25	464	79.0	35.8
KCPSA-11	562	618	628	638	644	5.59	142	10.44	265	18.25	464	96.0	43.5
KCPSA-13	675	743	755	766	773	6.59	167	10.44	265	18.25	464	113.0	51.3
KCPSA-15	787	1011	1031	1047	1060	8.53	217	10.44	265	18.25	464	139.0	63.0

Recommended end of charge voltage — 2.50 to 2.55 volts per cell @ 77°F (25°C)
Specific gravity @ 77°F (25°C) — full charge — 1.300
Recommended start of charge current — up to 20 amperes per 100 AH rated 8 Hr. capacity

FIGURE 3.5-2 : CHARACTERISTICS OF C&D 3KCPSA-5

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OF POOR QUALITY

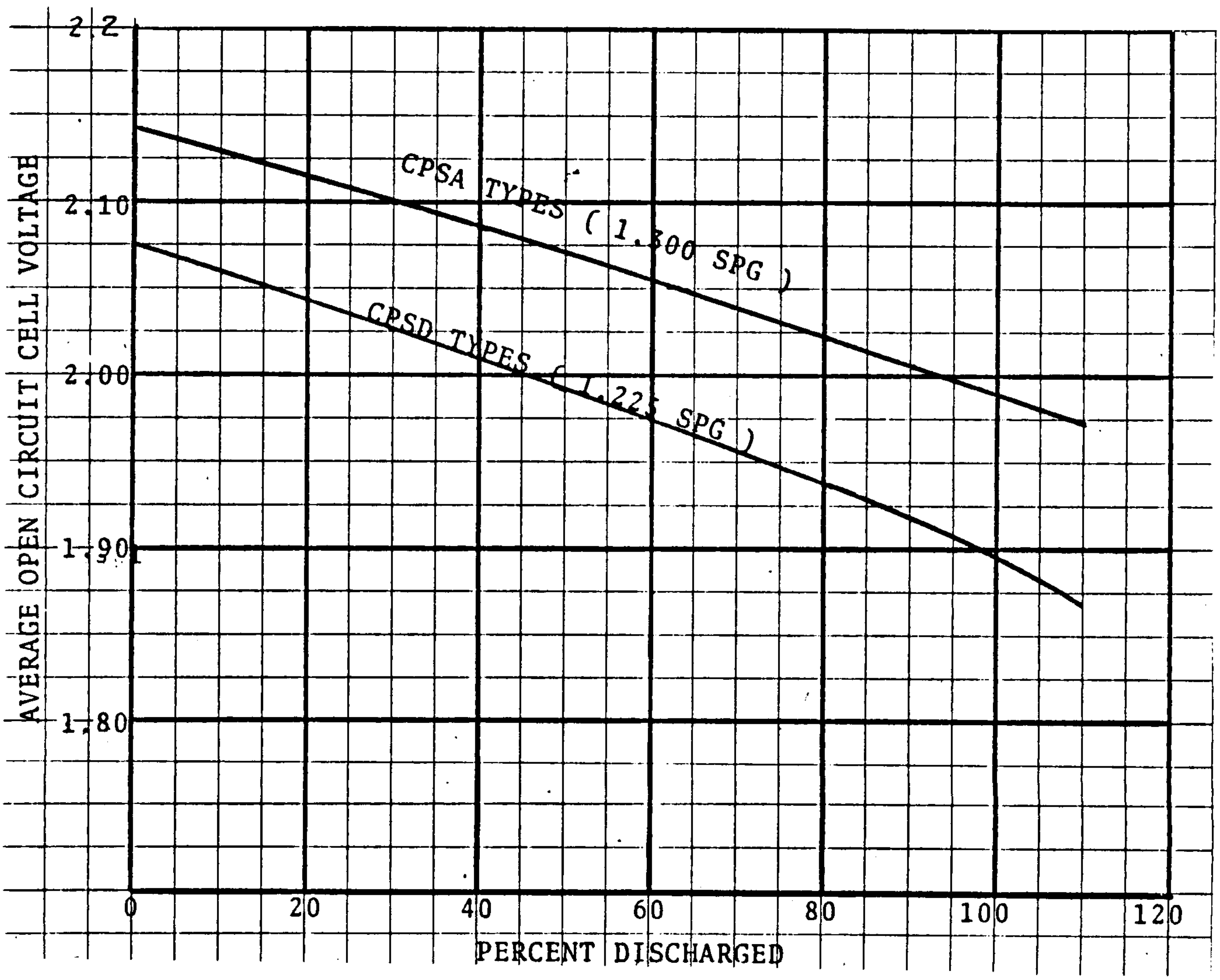


Figure 3.5-3. Approximate Open Circuit Voltage of a Shallow Cycle C & D Battery Cell at Various Depths of Discharge

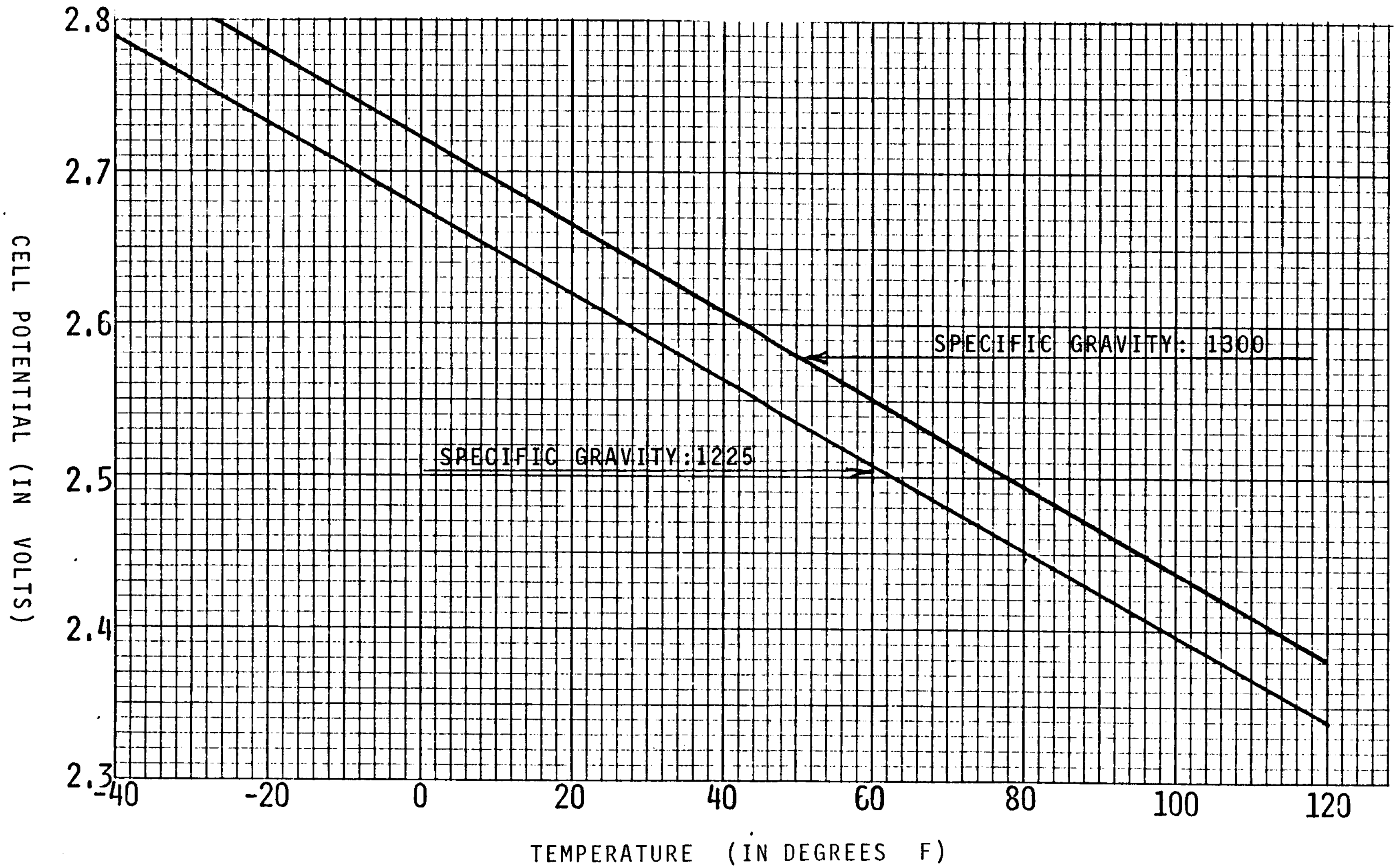


FIGURE 3.5-4 RECOMMENDED FLOAT VOLTAGE RANGE FOR CELLS OF SHALLOW CYCLE TYPE C & D BATTERIES AT VARIOUS TEMPERATURES

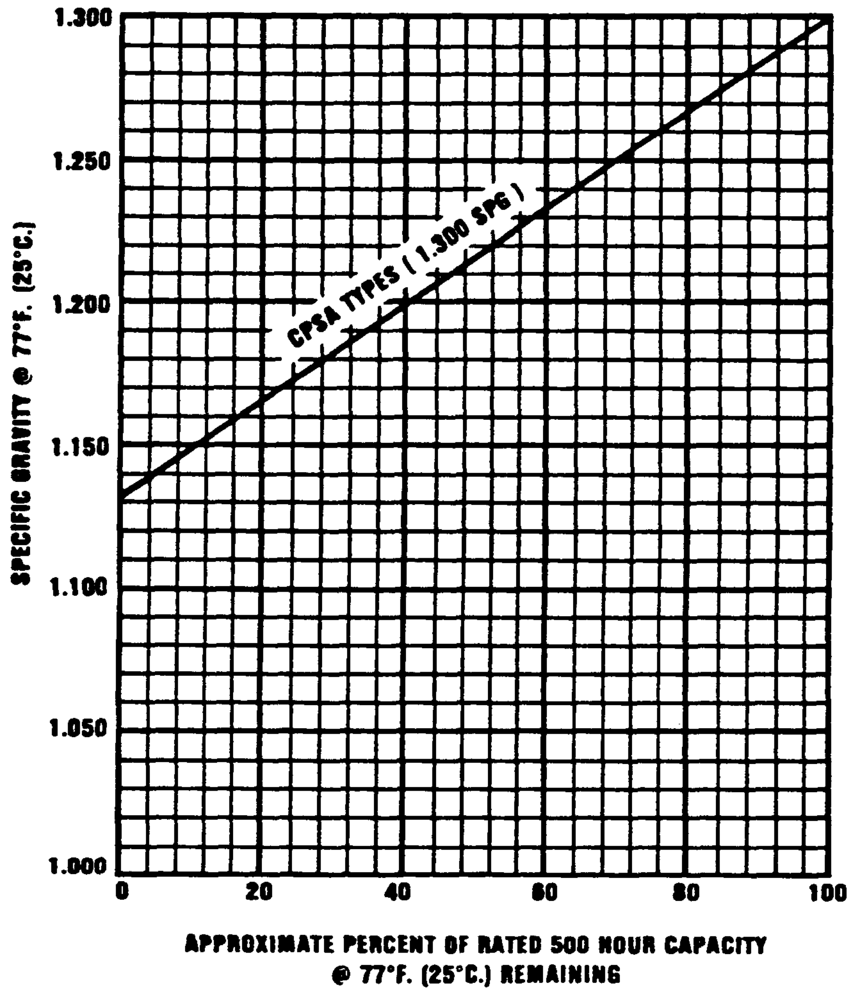


FIGURE 3.5-5 **APPROXIMATE 500 HR. RATED CAPACITY REMAINING VS. SPECIFIC GRAVITY**

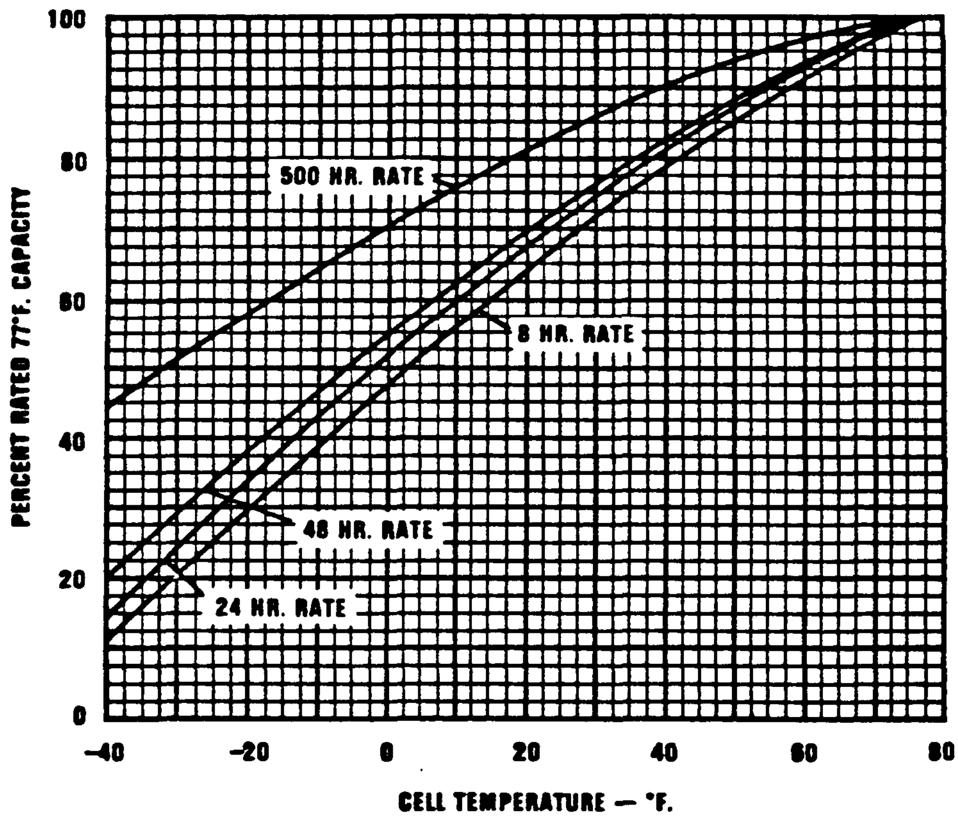


FIGURE 3.5-6 AMPERE-HOUR CAPACITY OF A TYPICAL SHALLOW CYCLE C&D CELL AS A FUNCTION OF ELECTROLYTE TEMPERATURE

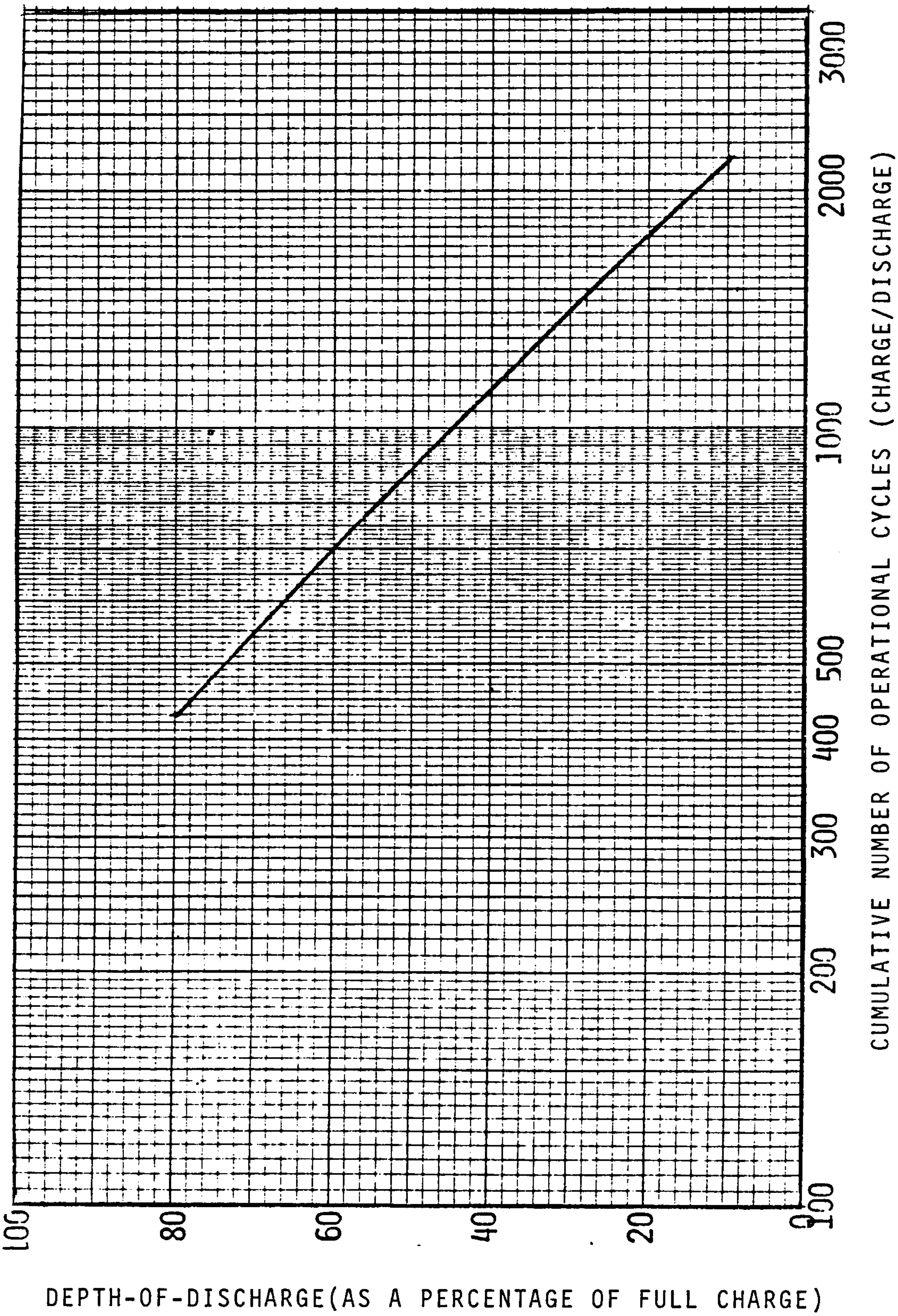


FIGURE 3.5-7 REPETITIVE CYCLE LIFE OF BATTERY AS A FUNCTION OF THE DEPTH-OF-DISCHARGE

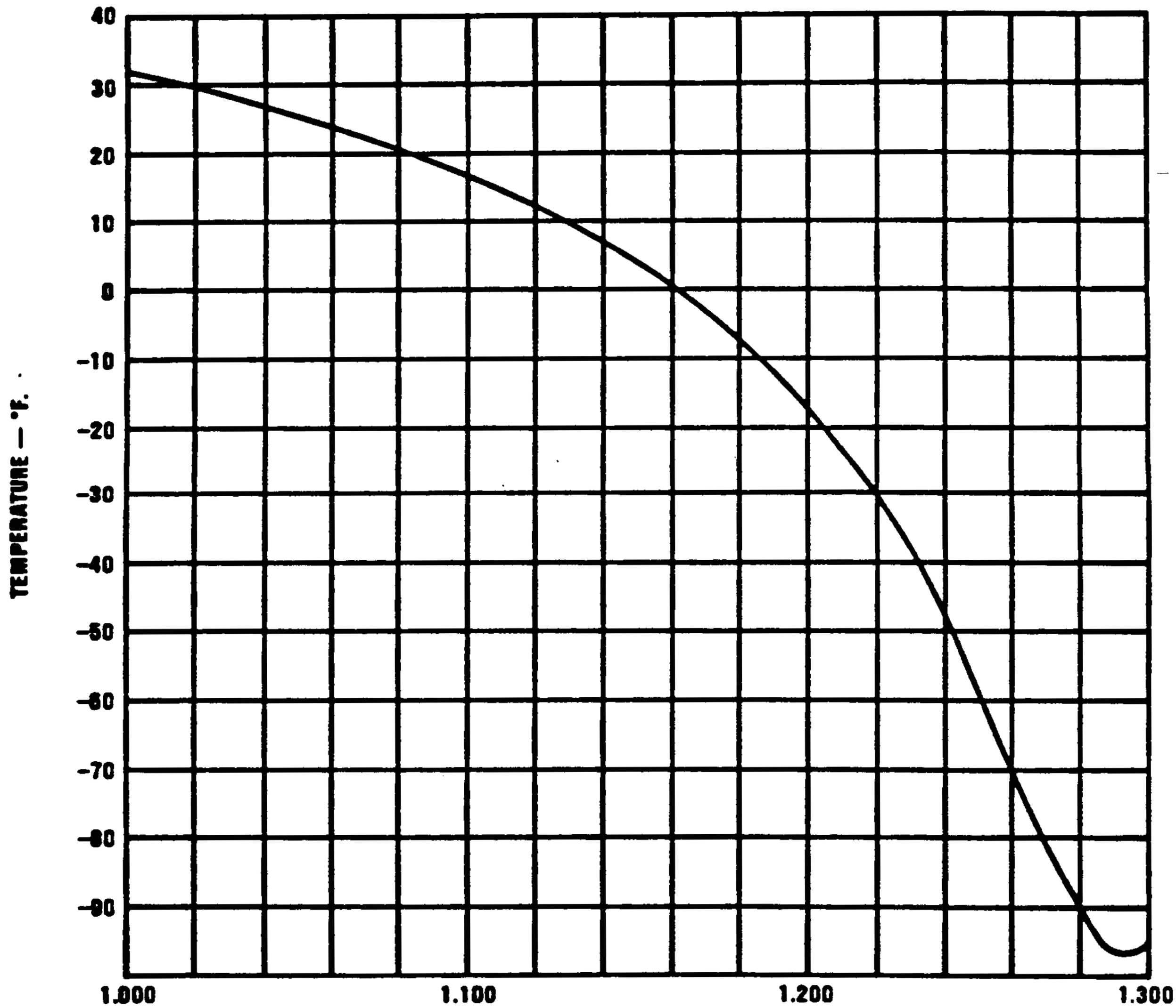
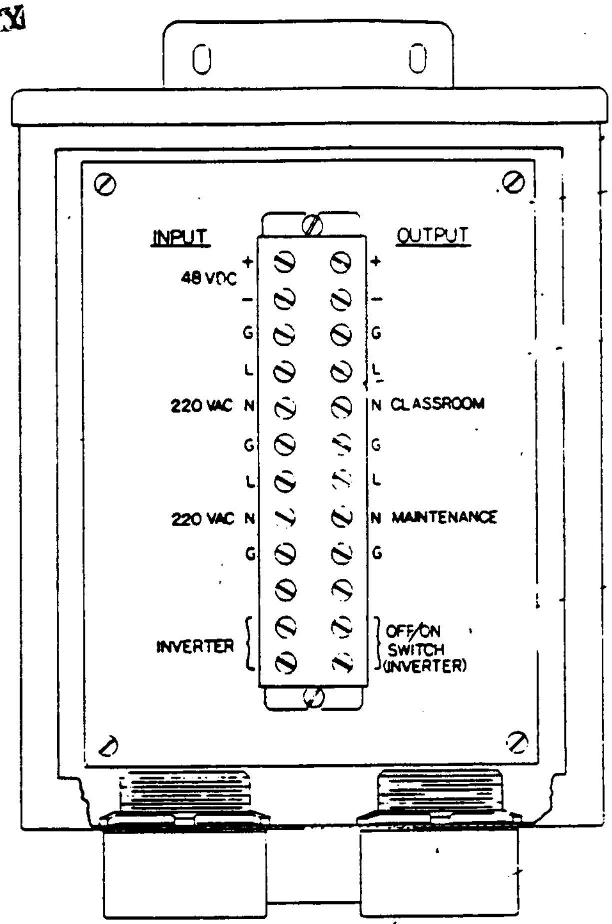


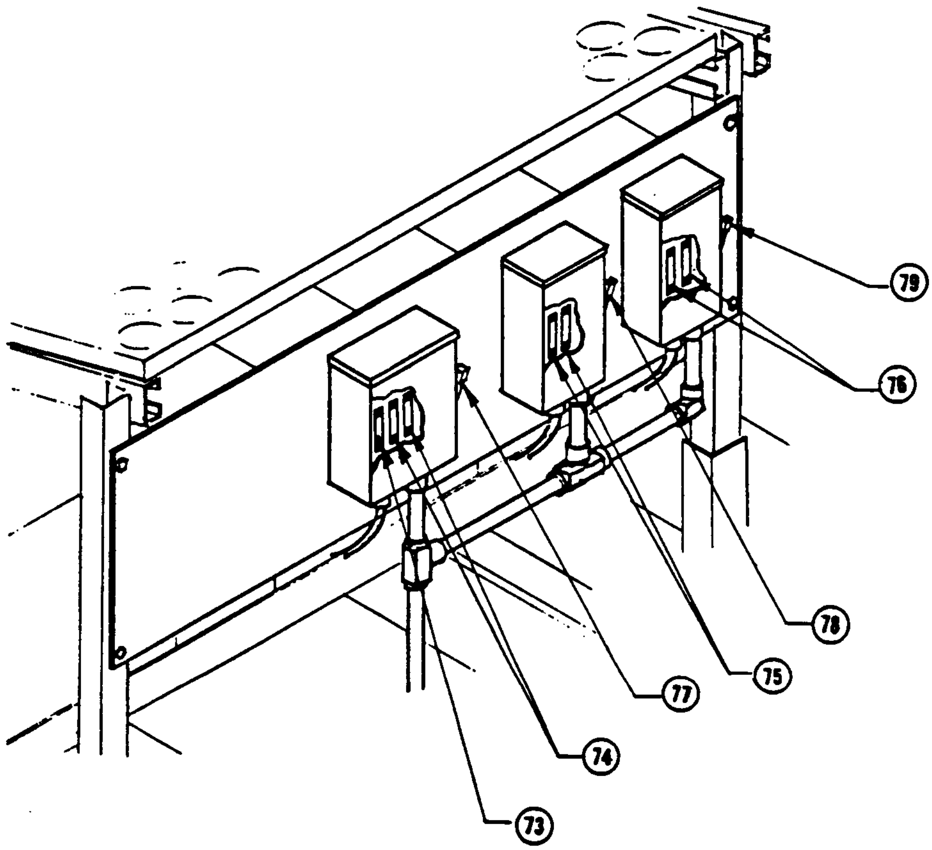
FIGURE 3.5-8 **FREEZING POINT OF H_2SO_4 ELECTROLYTE VS. SPECIFIC GRAVITY**



The Interface Box (Panel)

- Provides a remote elecrical tie between the power system and the Earth Station/classroom loads.
- Includes 60 Vdc, as well as 50 Hz 230 V_{ac} for classroom and maintenance.
- Includes remote control switch line for inverter.

FIGURE 3.5-9 THE INTERFACE BOX



LEGEND:

NUMBER	ITEM	NUMBER	ITEM
73.	FUSE FOR POWER CONTROL EMERGENCY SWITCH	77.	SAFETY SWITCH FOR BATTERY #1
74.	FUSES FOR BATTERY #1	78.	SAFETY SWITCH FOR BATTERY #2
75.	FUSES FOR BATTERY #2	79.	SAFETY SWITCH FOR BATTERY #3
76.	FUSES FOR BATTERY #3		

FIGURE 3.5-10 BATTERY SAFETY SWITCHES

Table 3.6-1 following summarizes the salient design and performance characteristics of the GENSET. Figure 3.6-1 is a photo of the equipment with the enclosure removed; Figure 3.6-2 is an outline drawing identifying the major components, while Figure 3.6-3 is a photograph of the GENSET (with weatherproof enclosure), installed in the Wawatobi equipment bay.

Figure 3.6-4 is a schematic of the remote, automatic start-up circuitry installed in the GENSET. These relay circuits perform the following functions:

1. Accept the automatic "start" signal from the power controller, turning on the intake manifold preheaters.

2. Time-out the preheat time required to ensure reliable "first-start".

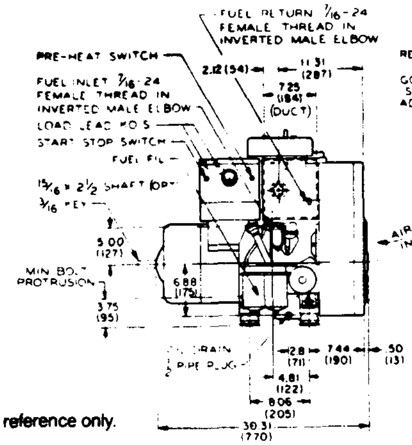
3. At the end of the prescribed pre-heat period, close the fuel pump and starting solonoid circuits.

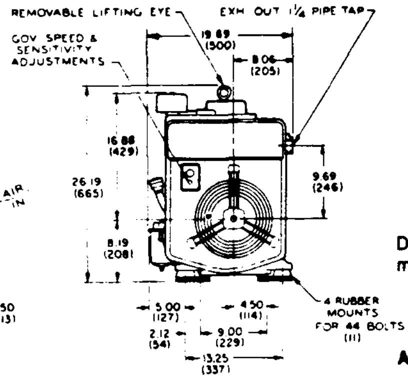
In the event of failure to start the controls, after a described delay, the GENSET automatic controls will shut down, and reset, awaiting another starting event. The power controller circuits are not however programmed for more than one successive start-up attempt. After one start-up failure the system will continue to operate on battery.

3.7 The Alarm Box

The alarm box consists of a red dome flasher and a weather resistant pulsating siren. The red dome flasher operates on a 48 VDC input from the batteries. The pulsating siren operates on the same voltage passed through a 60 ohm resistor to provide a 12 VDC source. The alarm box turns on automatically under two conditions. The first is during a low level of charge on the batteries and a failure of the GENSET to start. The second is when an over voltage (62.5 VDC) exists on the power bus. Figure 3.7-1 depicts the apparatus.

Basic Dimensions





Dimensions in inches; millimeters shown in parentheses

Approximate net weight: 348 lb (157.8 kg)

Caution: this drawing supplied for reference only.

Operating Data 3.0 DJA

Hertz	Engine Power Min. bhp (kW)	Piston Speed fpm (mm/s)	Cooling Air-cfm (m³/min)	Combustion Requirement Air-cfm m³/min	Generator Cooling Air-cfm (m³/min)	Average Fuel Consumption #2 Diesel, gph (L/h) at load- 0	1/4	2/4	3/4	4/4
60 (1800 r/min)	5.7 (4.25)	1087 (5522)	440 (13.59)	16 (0.45)	75 (2.12)	0.21 (0.64)	0.23 ( )	0.26 (0.98)	0.29 ( )	0.34 (1.29)
50 (1500 r/min)	4.5 (3.36)	906 (4601)	367 (10.38)	13.3 (0.38)	63 (1.78)	0.17 (0.64)	( )	0.24 (0.91)	( )	0.29 (1.10)

Generator Detail

Design: Onan AC revolving armature, 4-pole, self excited, inherent voltage regulation
Drip-proof construction
Permanently aligned to engine through rigid coupling
Battery Charging: 12V fused DC starting battery charging circuit with adjustable charge rate 2 to 5 amp
Negative ground only
Frequency Regulation: 3-Hz (5%) no load to rated load
Insulation: Class B per NEMA MG1-1.65, insulating varnish conforms to MIL-I-24092
Temperature Rise: Within NEMA MG1-22.40 at rated load

Cooling: Direct drive centrifugal blower
Electromagnetic Interference Level: Attenuation exceeds requirements for most civilian and commercial applications
Capacitors on all ungrounded brushes
Armature: Laminated electric steel stack, keyed and press fitted to shaft
Heavy insulated copper wire windings
Balanced
Stator: Laminated electrical steel pole shoes mounted in rolled steel frame
Machine form wound and taped field coils
Bearing: Double sealed, prelubricated ball bearing

Engine Detail

Model: Onan DJA Diesel
Design: 4-cycle, single cylinder, vertical
Displacement: 30 in³ (491.6 cm³)
Bore: 3.25 in (82.55 mm)
Stroke: 3.625 (92.08 mm)
Compression Ratio: 19 to 1
Cooling: Pressure air cooled. Direct drive centrifugal flywheel blower
Fuel: Diaphragm transfer pump with hand primer
Fuel lift 6 ft (1.83 m)
Primary and secondary fuel filters mounted on engine

Lubrication: Positive displacement lube oil pump. Full pressure lubrication to main and connecting rod bearings
Oil capacity 3 qt (2.84 L) including filter
Starting: Remote, 12V 3-wire, negative ground
Bearings: Two main are steel backed bronze sleeves: replaceable precision inserts
Valves: Overhead, free to rotate

TABLE 3.6-1 SALIENT DESIGN AND PERFORMANCE CHARACTERISTICS OF ONAN DJA DIESEL GENSET

SERIES

DJA

GenSet

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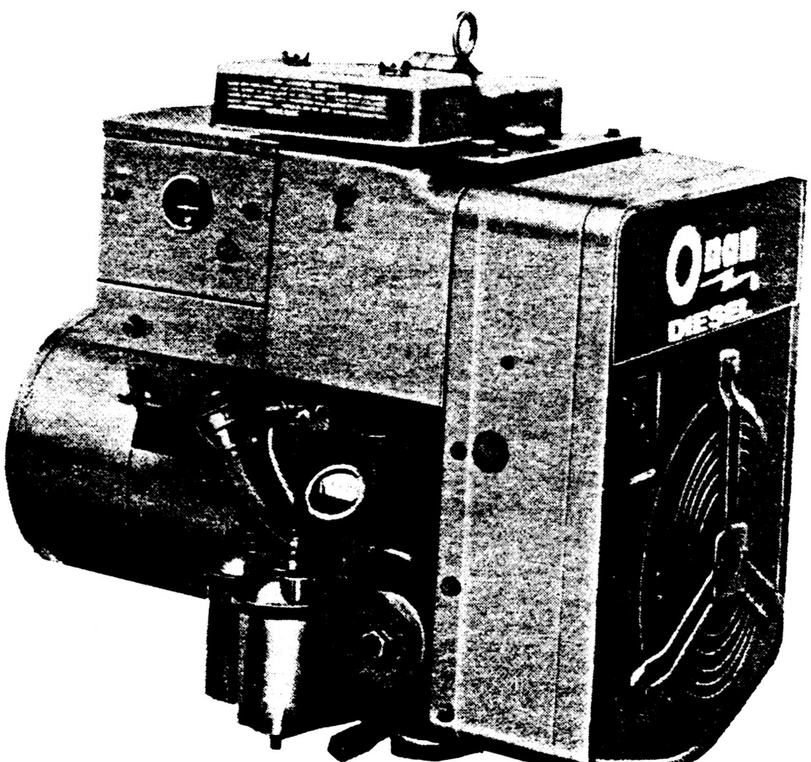
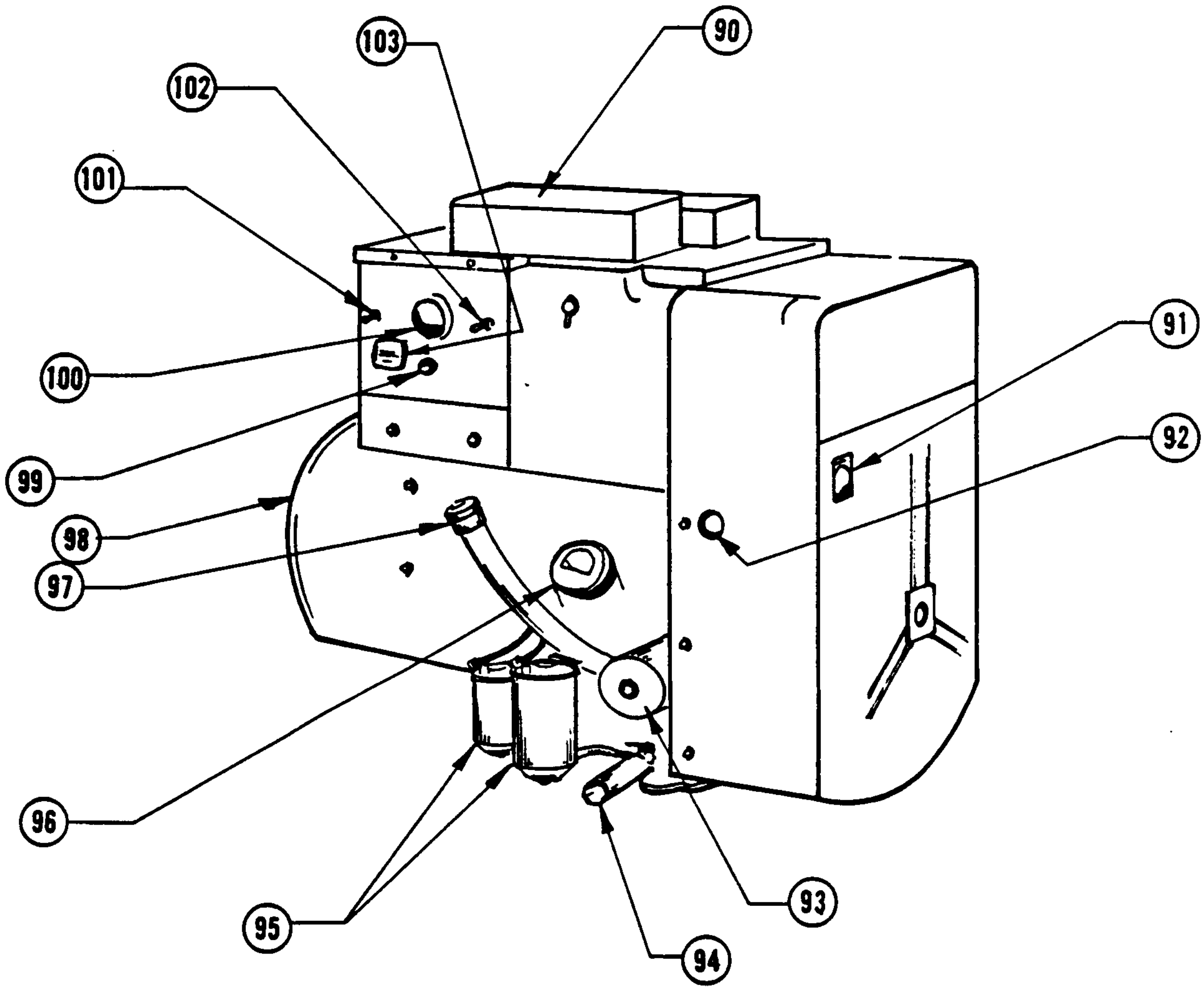


Figure 3.6-1. ONAN Technical Bulletin: Photo of 2.4KW GENSET with Enclosure Removed



LEGEND:

NUMBER	ITEM	NUMBER	ITEM
90.	AIR CLEANER	97.	OIL FILLED TUBE
91.	SPEED GOVERNOR	98.	AC GENERATOR
92.	SENSITIVITY ADJ	99.	FUSE
93.	OIL FILTER	100.	CHARGE RATE AMMETER
94.	OIL DRAIN	101.	START/STOP SWITCH
95.	FUEL FILTERS	102.	PREHEAT SWITCH
96.	OIL PRESSURE GAUGE	103.	RUNNING TIME METER

Figure 3.6-2. GENSET

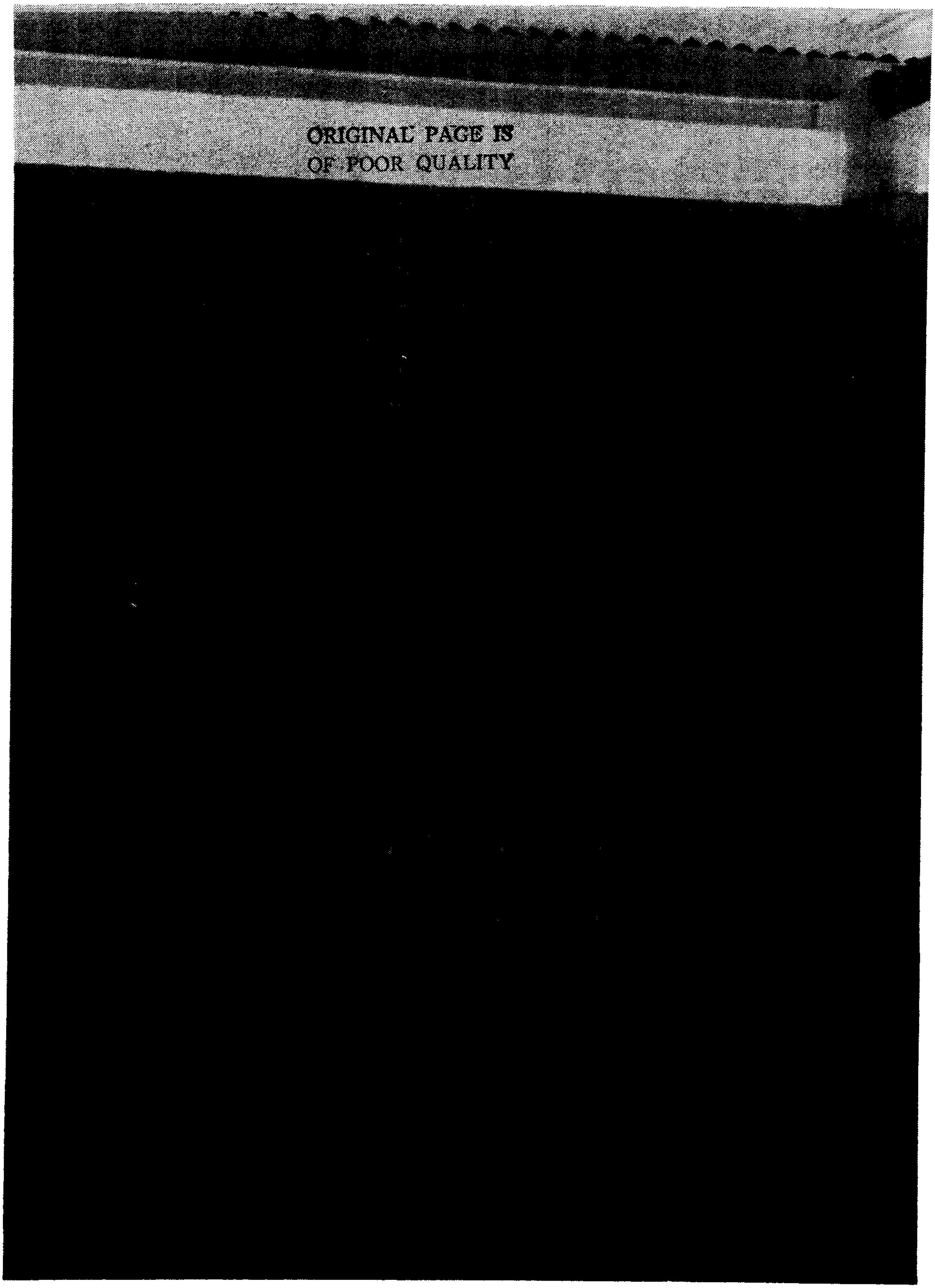
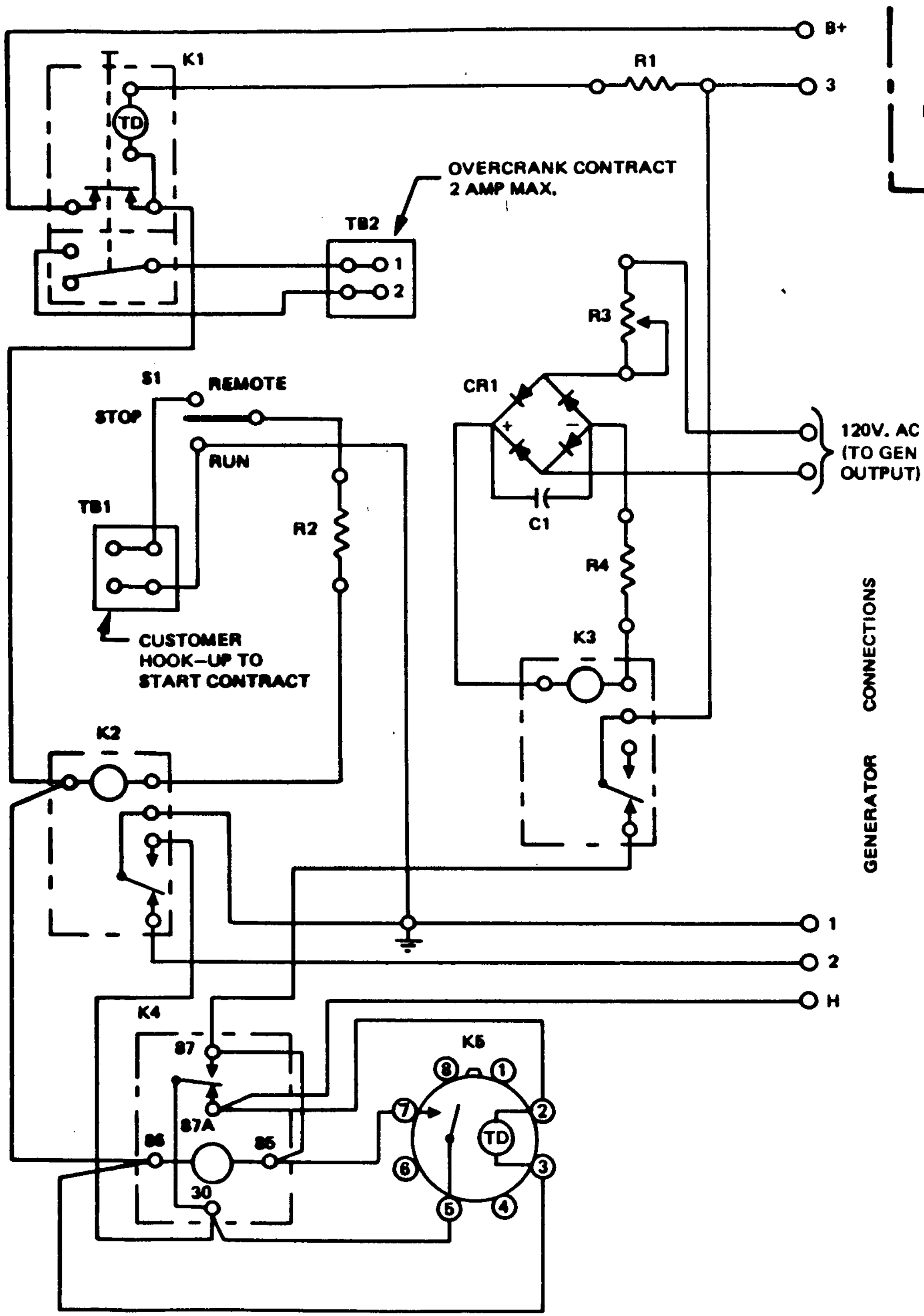


Figure 3.6-3. Photo of GENSET Bay



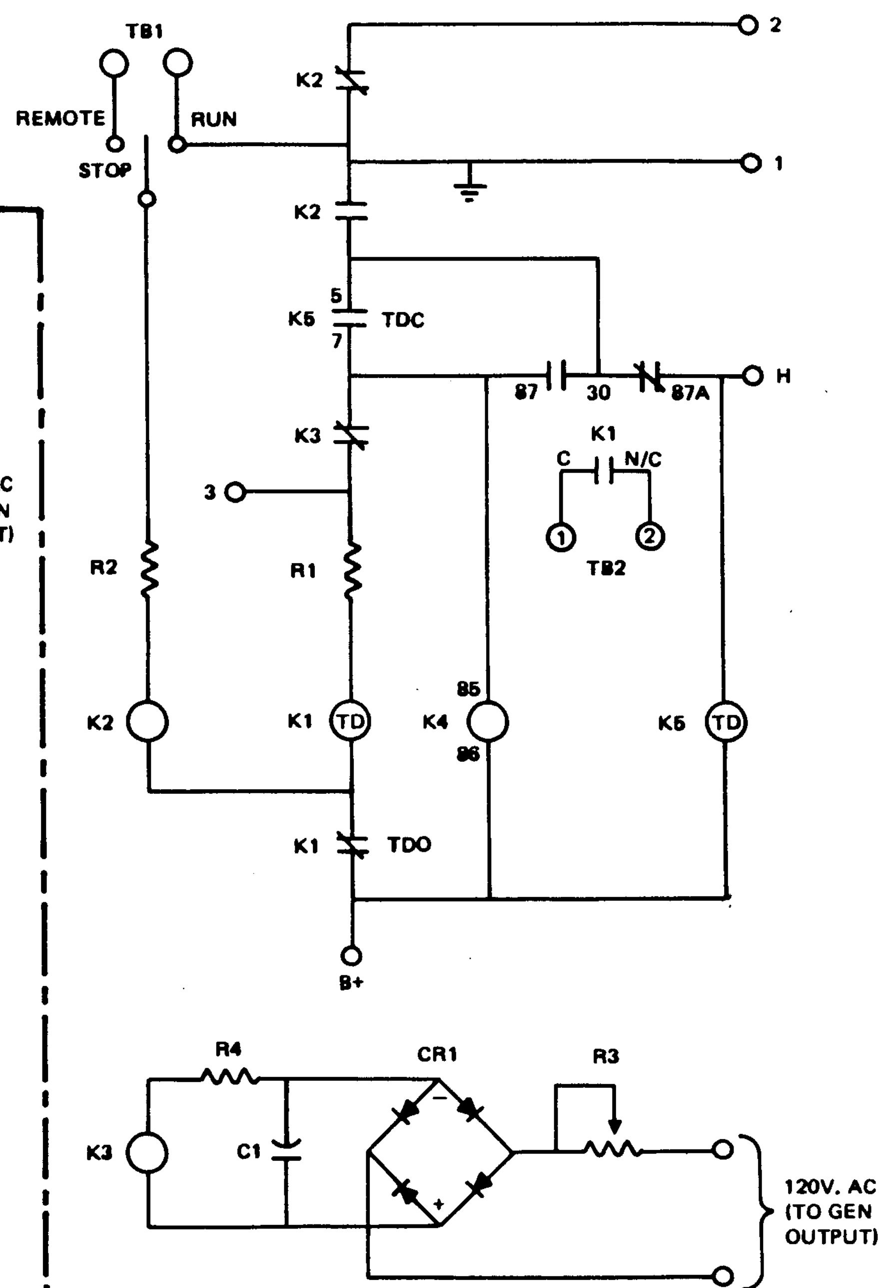
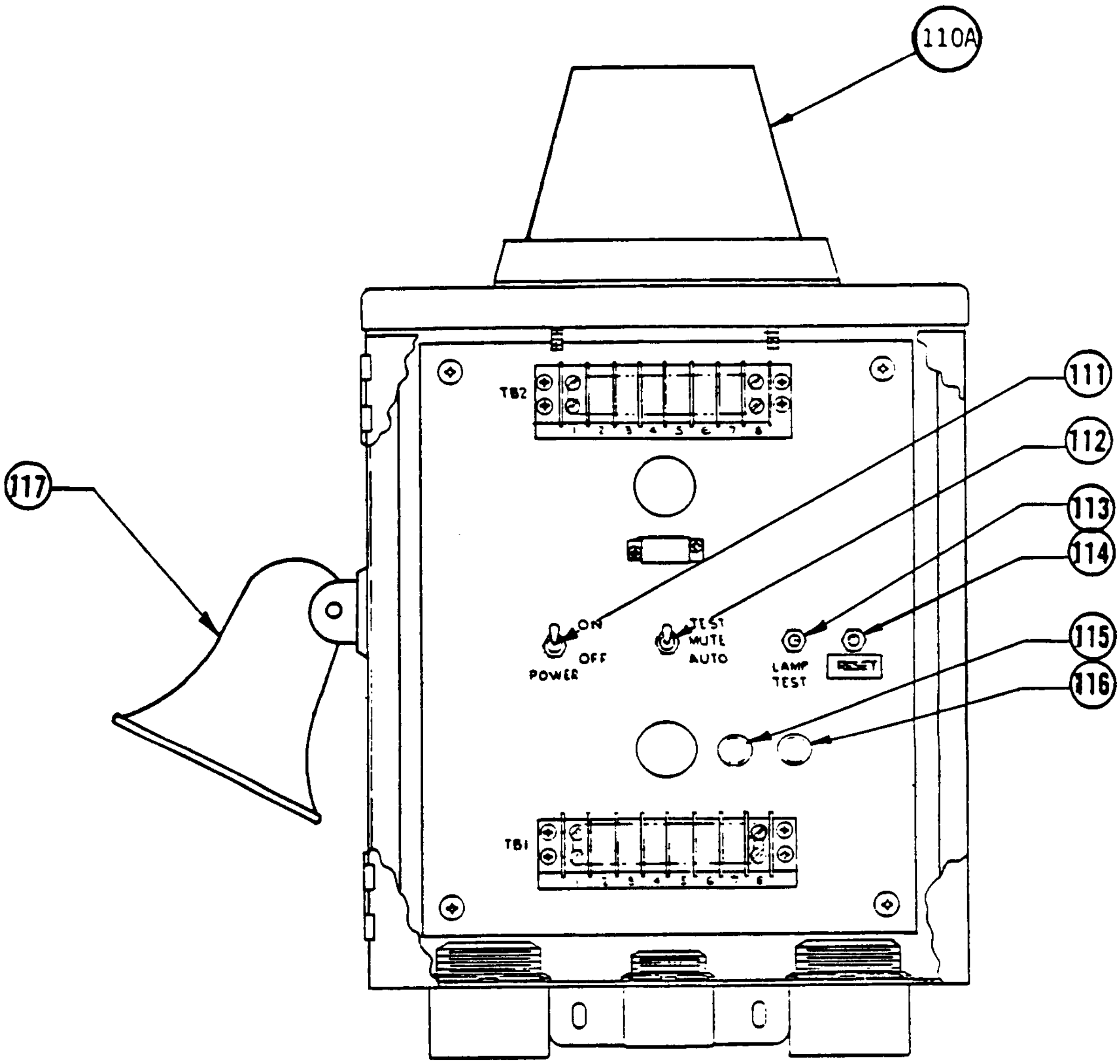


FIGURE 3.6-4 WIRING DIAGRAM AND SCHEMATIC OF CONTROL ADAPTER KIT FOR REMOTE GENSET START-UP/SHUT-DOWN

Table 3.6-5 below identifies the control adapter kit electrical parts.

Table 3.6-5. Parts List

REF. DES.	PART NO.	QTY	DESCRIPTION
K1	320B104	1	RELAY-CRANKING LIMITER
K2	307B1052	1	RELAY-START STOP
K3	307-645	1	RELAY-T.D. PREHEAT
K4	E520-258	1	RELAY
	304-580	2	INSULATOR
R1	304A192	1	RESISTOR-352, 10W
R2	304A251	1	RESISTOR, 3052,5W
51	308-138	1	SWITCH, SELECTOR
TB1	332A609	1	BLOCK-TERMINAL
	332A1003	1	STRIP-MARKER
W11-W5	338A551	1	LEAD ASSY, 32"LG
	332-1178	3	TERM-FAST ON



LEGEND:

NUMBER	ITEM	NUMBER	ITEM
110.	RED LIGHT	114.	RESET
111.	POWER ON/OFF	115.	FUSE
112.	TEST MUTE AUTO	116.	FUSE
113.	LAMP TEST	117.	SIREN

Figure 3.7-1. Alarm Box

4.0 SYSTEM POWER CONTROL OPERATIONS

This section of the Design Description Report covers mechanization of the power system from the point-of-view of the user or operator. Major controls and displays are further identified and the importance of proper functional interpretation and correct reaction by the operator is emphasized for clarity. A number of the illustrations previously given are repeated or referenced.

4.1 OVERVIEW

Under Section 2.2, the three basic operational modes were described: MODE I - FULL AUTOMATIC, PHOTOVOLTAIC (PV) Array and GENSET power; MODE II - AUTOMATIC/PV power only; MODE III - GENSET power only. MODE I is the preferred mode of operation, the Photovoltaic Power System operates completely unattended. The PV Array generates electric current in proportion to the amount of sunlight available; the greater the amount of sunlight the more current that is generated. Shrubs, trees, and other foliage structures nust not block the sun rays from the PV panels. If this happens, only a limited amount of PV power will be generated and the GENSET will run almost all of the time.

With the exception of the manually operated circuit breakers and switches, most of the functions are automatic. The PV Array current charging the Battery is cycled OFF/ON in accordance with the Battery voltage. The GENSET comes ON automatically when the Battery voltage has dropped below a preset level. The GENSET turns OFF automatically when the Battery has recharged enough to cause the Battery voltage to reach another preset limit. Both the GENSET and the PV Array disconnect if the Battery voltage climbs to dangerous levels. Similarly all loads are automatically shed when the Battery voltage drops to levels indicating near total discharge.

MODE II is an extension of MODE I; the power is supplied only by the PV array, and the GENSET is not available to provide back-up power. The GENSET may be out of service for repairs or preventative maintenance. MODE II operations are also required if the Battery Charger has failed. MODE III is the least preferred mode and is used only when the PV array, the battery and most of power controller circuits have failed or are not operating. All power is provided only by the GENSET. Figure 4.1-1 following is a ladder diagram of the power relaying functions.

4.2 CONTROLS AND DISPLAYS

Section 4.2 further identifies the operational controls and display of the power system. With the exception of the GENSET controls (which are exclusively concerned with manual operation and maintenance), and those on the auxiliary alarm and safety switchgear enclosures, all essential operational controls are concentrated on the several panels of the power controller. These display and control panels include the PCP (Power Control Panel), the POP (Power Output Panel), the Instrumentation and Diagnostics Panel, and those on the DC Battery Charger. The test points on the panel for the PSM (Power Switching Module) are identified. The voltage thresholds corresponding to various control actions were previously given in Figure 2.2-1 preceeding.

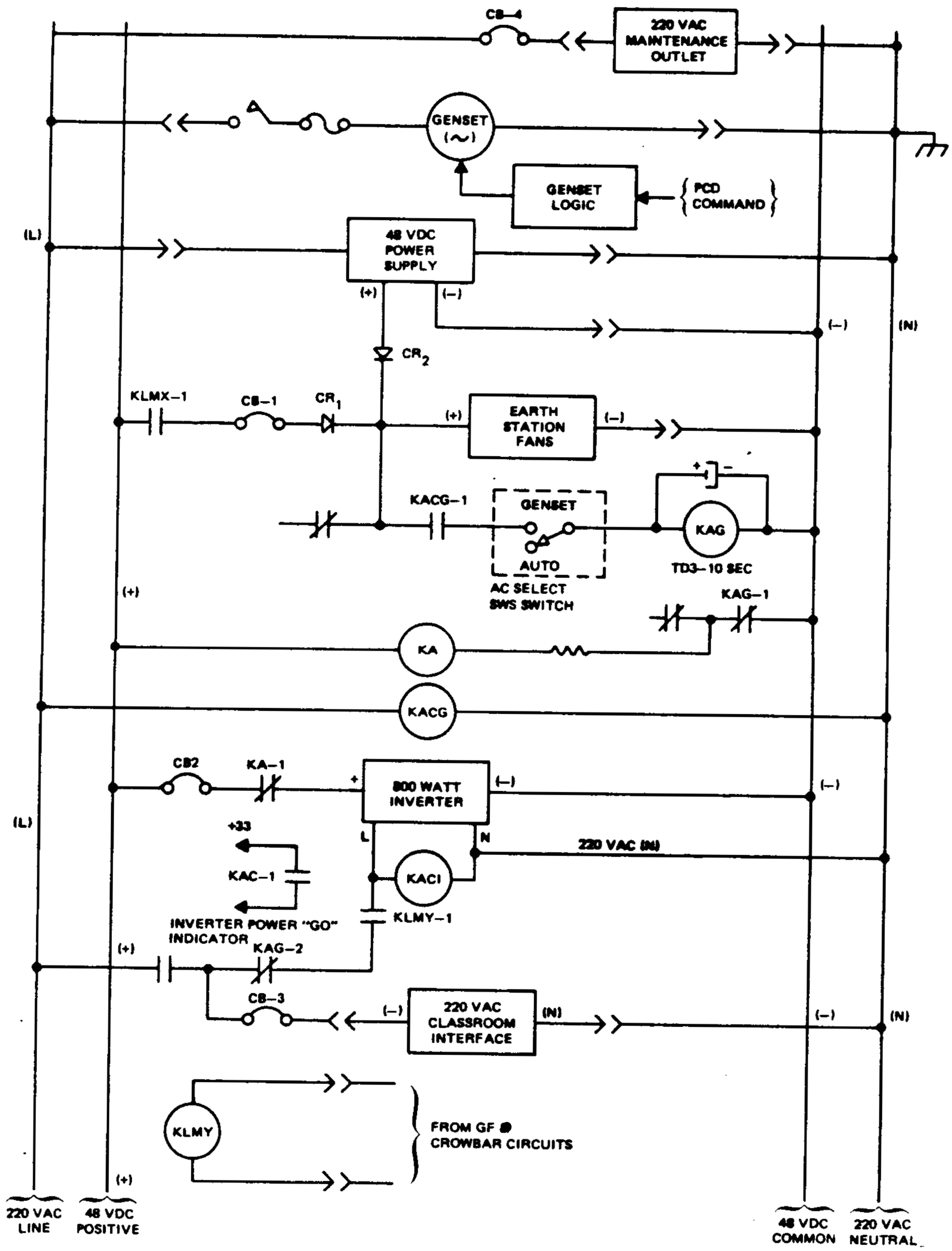


FIGURE 4.1-1 LADDER DIAGRAM OF SYSTEM POWER RELAYING

4.2.1 Displays on the Power Control Panel (PCP) (Figure 3.4-4 of Section 3.0)

Items one (1) through (12) of Figure 3.4-4 are status lights. The following listing identifies the function of each.

- o Lights (1) (Amber) and (2) (Green) indicate that power is being delivered from one-half of the PV Array, Channel "A".
- o Lights (3) (Amber) and (4) (Green) indicate that power is being delivered from one-half of the PV Array, Channel "B".
- o Light (1) (Amber) indicates that the Battery has been recharging normally and is now fully charged (has reached float voltage).
- o Light (2) glows Green when the Battery can/is receiving power through Channel "A". (The Battery bus voltage is below the float-cycle level.)
- o Light (4) glows Green when the Battery can/is receiving power through Channel "B". (The Battery bus voltage is below the charge taper level.)
- o Light (5), a warning indicator, glows red when the crowbar is closed and the PV Array is shorted out.
- o Light (6), a warning indicator, glows red when the battery bus voltage drops to a low level (undervoltage), close to battery depletion.
- o Light (7), a warning indicator, glows red if the battery bus voltage reaches, a dangerously high level (overvoltage).
- o Light (8), warning indicator, glows red and warns that the GENSET has failed to start upon command. The GENSET is locked out and the alarm is turned on.
- o Light (9), glows white when the PV Array circuits are generating power.
- o Light (10) glows white when the GENSET is powering the Battery Charger.
- o Light (11), glows white when the Inverter is delivering AC power the classroom. Light (11) will never light up if the GENSET is on.
- o Light (12) glows white, indicating that the GENSET is ON, delivering power.
- o Light (31) in the Emergency/Control power push button switch glows white when DC control power is ON.
- o Meter (15) is the bipolar DC Ammeter. When its pointer is to the left of the center it indicates the magnitude of the battery discharge current; to the right of center it indicates charging current. When the needle is centered, there is no current flowing, or the charge current is equal to the discharge current demanded by the load.

4.2.2 Controls on the Power Control Panel (PCP)

All of these functional controls are directly accessible. The reference numbers are those given on Figure 3.4-1, the PCP front panel layout. Normal daytime operation with adequate PV power is assumed.

- Switch (13) is a monentary contact, push-button switch that resets the crowbar [indicated by red light (5)] after a ground fault has been cleared.

- Switch (14) is a push button switch that resets the undervoltage or overvoltage circuits [indicated by red lights (6) or (7)] when conditions have been restored to normal.

- Switch (16) permits selection of the AC power source for the Classoom load. The Inverter will not work however if the GENSET is ON.

- Fuses (17) show the location of the control power fuses.

- Switches (18(, (19), (20), (21), (22), (23) and (24) are test switches. They are momentary contact toggle switches, with the center position "OFF". If the control circuits are working properly, the display lights should respond as follows:

- Switch (18) tests PV regulator Channel "A". In the UP position Light (2) should go OFF and Light (1) should come ON. In the DOWN position (1) should go OFF and (2) ON.

- Switch (19) tests PV regulator Channel "B". In the UP position, Light (4) goes OFF, and (3) ON. In DOWN position, (3) goes OFF and (4) goes ON.

- Switch (20) checks the UNDERVOLTAGE protective trip. The UP position simulates an undervoltage condition; Light (6) (red) goes on if trip is successful. Reset of (14) required.

- Switch (21) is for the OVERVOLTAGE protective trip. The UP position will simulate an overvoltage condition. Light (7) (red) goes on if trip is successful. Reset of (14) required.

- Switch (22) in the UP position will test the GENSET starting system. Light (10) (white) will turn on if the system is okay.

- Switch (23) tells the controls to shut OFF the GENSET and lets the system return to normal daytime operation.

- Switch (24) in the UP position simulates an array ground fault that trips the CROWBAR. Light (5) (red) goes on and the crowbar must be reset by depressing pushbutton (13).

The balance of the controls of the PCP are concerned with Mode Control. The Mode Control switch positions are the same for (25, 26, 27, 28, 29, 30) pushing each toggle switch UP disconnects the function. Pushing each toggle switch DOWN by-passes the automatic control and places the function in an energized state as follows:

(25) UP stops charging from PV circuit channel A. Light (1) may go OFF and light (2) ON.

(25) DOWN keeps float charging PV current flowing even when not needed.

(26) DOWN keeps taper charging current flowing even if not needed.

(26) UP stops charging from PV circuit channel B. Light (3) may go OFF and light (4) may go ON.

(27) UP disconnects undervoltage safety trip.

(27) DOWN simulates an undervoltage condition; red light (6) should glow and the battery should be disconnected from the bus.

(28) UP keeps a safety overvoltage trip from taking place.

(28) DOWN disconnects both power sources and will not let either deliver power.

(29) UP will prevent the GENSET from starting.

(29) DOWN starts the GENSET and keeps it ON.

(30) UP will prevent the crowbar* from tripping.

(30) DOWN energizes the crowbar and keeps it closed.

* The crowbar is a relay which short circuits the PV array.

4.2.3 <u>Displays on the Power Output Panel (POP)</u> (Figure 3.4-5 of Section 3.0)

Figure 3.4-5 following identifies the controls, displays status indicators on the Power Output Panel (POP). Key numbers are used to identify POP functions in the descriptions following.

Meter Vrms (54) is a voltmeter that displays the level of the voltage on the output AC bus. It should read between 225 and 240 VAC.

Meter Irms (55) displays the AC current drawn by the classroom load.

Meter (56) indicates the frequency of the AC power in hertz.

CBs (58) and (59) are circuit breakers which disconnect DC to the station and DC from the inverter, respectively. They are to be returned to the up position when the fault is cleared.

CBs (60) and (61), the AC Ground Fault Interrupters, signal a AC ground fault by releasing of a trip-indicating flag which opens the load circuit.

4.2.4 <u>Controls on the Power Output Panel (POP)</u>

Switch (57) permits the inverter AC to be turned ON and OFF. The Ground Fault Interrupters (60) and (61) trip open when an object or person accidently form a circuit between the AC line and ground.

Receptacles (62) (63) and (67) are the plus safety disconnects for the three Battery strings. The negative disconnects, (64), (65) and (66) are the smaller one located below the larger connector-plug combinations. They are called "SUPERCONS" which is the manufacturers way of identifying them.

4.2.5 Power-Switching Module (PSM) (Figure 3.4-3 of Section 3.0)

Figure shows the front panel layout of the Power Switching Module. There are no displays on this panel. Key designations (40) through (51) are diagnostic test points for use by troubleshooting and repair personnel. These should be ignored since they are not involved in routine operations.

(52) is a circuit breaker in the channel A PV Array circuits that feed the "A" regulator channel.

(53) is an identical circuit breaker in the channel B PV Array circuits that feed the "B" regulator channels.

4.2.6 Instrumentation Panel

The Instrumentation Panel, shown in Figure 3.4-7, does not have any controls except for the reset buttons on each of the six ampere-hour accumulators, (84) (85) (86) (87) (88) (89). The displays are all either DC ammeters (80) (81) (82) or a voltmeter (83). One DC ammeter (80) indicates the total current output of all of the PV source circuits. Meter (81) displays the instantantous current delivered by the Battery Charger. Total DC load current is measured by reading (82). The battery bus voltage is indicated on a DC voltmeter (83). Counter (84) displays the cumulative ampere-hours delivered to the Battery.

The cumulative ampere-hour taken out of the battery may be read on counter (86). The total ampere-hours of electricity produced by the Battery Charger are displayed on counter (87). The ampere-hours accumulated in powering the Inverter are displayed on counter (88), and the total ampere-hours consumed by the Earth Station DC load are displayed on counter (89).

4.2.7 Battery Charger (Figure 3.4-8 of Section 3.0)

The Battery Charger is powered by the GENSET. It operates only when the GENSET is ON. It has several controls and displays on the front panel. Meter (32) is a voltmeter that reads the voltage produced by the charger. It will be a little higher than the battery bus voltage. Meter (34) is the built-in DC ammeter in the charger. It will read the same as ammeter (82) on the Instrumentation Panel.

4.2.8 GENSET (Figure 3.6-1 through 3.6-4 of Section 3.0)

The Back-Up GENSET is very important. It powers the DC Earth Station load and provides 230 VAC 50 HZ power to the classroom when the system battery has not been recharged by solar PV power. It is the only source of AC maintenance power. The normal mode of operation is either AUTOMATIC or MANUAL. In the event of a serious problem or an emergency, the service technician must be called immediately. The GENSET is shown in Figure 4.2-7. Item (90) is the air cleaner; (91) is a speed governor that controls engine RPM and thus AC frequency; (92) is an adjustment that only should be touched by a maintenance person; (93), (94), (95), and (97) are part of the oil and and fuel systems; (96) is an oil pressure gauge; (99) is a fuse in the GENSET battery circuit; (100) the GENSET battery charger rate ammeter. Switch (101) is the manual start-stop switch and (102) the preheat switch. These two local controls are by-passed (Locked-Out) in normal automatic mode operation. Switch (103) is the running-time meter on the diesel engine which indicates engine operation, not generator power delivery.

4.2.9 Alarm Box (Figure 3.7-1 of Section 3.0)

The Alarm Box shown in Figure 3.7-1 is a separate waterproof enclosure that houses the audio alarm and red warning light. The light, (110A) is installed in a waterlight transparent housing. The electric horn, a solid state siren (117) is mounted on the side of the enclosure. (112) is a muting switch to permit horn testing. (113) is the lamp test pushbutton. The alarm circuits are of the lock-out type. After an emergency trip, the circuits are reset by pushing the reset pushbutton (114). The system is fused by (115) and (116).

4.2.10 Battery Safety Switches

The Battery Safety Switches, (77), (78), (79) as shown in Figure 3.5-10, are very important. Inside of these boxes are the fuses for each of the three Battery strings, (74), (75), and (76). The operators will not be called upon, however, to test or replace these fuses. These circuits are very hazardous and may only be worked on by troubleshooting and repair personnel. A separate line pair takes off from the first of the three Battery strings. The positive line is fused by (73). The line pair provides protected DC power for the control circuits. They will have power even if fuses (74), (75), and (76) clear.

4.3 OPERATIONAL STATUS ASSESSMENT

The power system operator has available sufficient displays, readouts and indicators to assess the status of the power system in all static and transitional states. The User/Operator Volume of the Technical Manual completely describes the status of all displays and indicators at all points in the complete cycle of turning on the system, operations under both normal and abnormal conditions, and during orderly shutdown. Please refer to subject manuals for detailed procedures.

5.0 PROJECT DOCUMENTATION

Project documentation falls under one of the four following categories:

- o Design Drawings - including mechanical, structural and electrical
- o Specification Control Drawings - documents controlling, the manufacture and/or procurement of hardware.
- o Industrial Manuals - vendor documentation in being, covering performance, design and service aspects.
- o Operations and Maintenance Data - including Operating and Service Manuals, Provisioning Information.

The status of each of these categories is summarized in Table 5-1 following.

Table 5-1
Status of Documentation

Documentation Category	Status
Final Design Drawings Mechanical and Structural Drawings Schematics and Wiring Diagrams Facility Drawings Site Pictorial Documentation	Post-installation and commissioning updated package has been sent to NASA and the customer.
Specification Control Drawings Module Procurement Specifications Battery Procurement Data Battery Charger Procurement Data Inverter Procurement Data GENSET Procurement	Module procurement specifications have remained substantially unaltered since hardware procured. This specification is part of the design documentation package.
Industrial Manuals Batteries Battery Charger Inverter ONAN GENSET	Industrial Manuals and Applications data provided by the manufacturer have been incorporated into Volume IV of the Operating and Service Manuals.
Operations & Maintenance (O&M) Documentation User/Operator Manual Operations and Maintenance Manual Troubleshooting and Repair Manual Other Operating Procedures	A complete set of manuals covering operation, maintenance, troubleshooting and repair have been completed and delivered to both NASA and the customer. These manuals have been updated to reflect several modifications made in the field after installation.

6.0 PROOF-OF-DESIGN TEST RESULTS

6.1 SUMMARY

Proof-of-Design Tests were conducted at Hughes/Long Beach in September, 1984. They were witnessed by a technical representative from the NASA/Lewis Solar Projects Office. The tests were successful, and the equipment, based upon the approved design, was released for shipment to Indonesia.

6.2 TEST SET-UP PROCEDURES

The test apparatus instrumentation and procedure employed in the Proof-of-Design Tests are set forth in the Test Plan, No. SEP 11624, which is included as Appendix A to subject report. Figure 6-1 following depicts the test setup.

6.3 SUMMARY OF RESULTS

Using the indicated NASA approved simulation power sources in lieu of the actual array as well as the deliverable battery complement, the Balance-of-System functional elements performed in full accordance with the requirements of the Acceptance Test Plan.

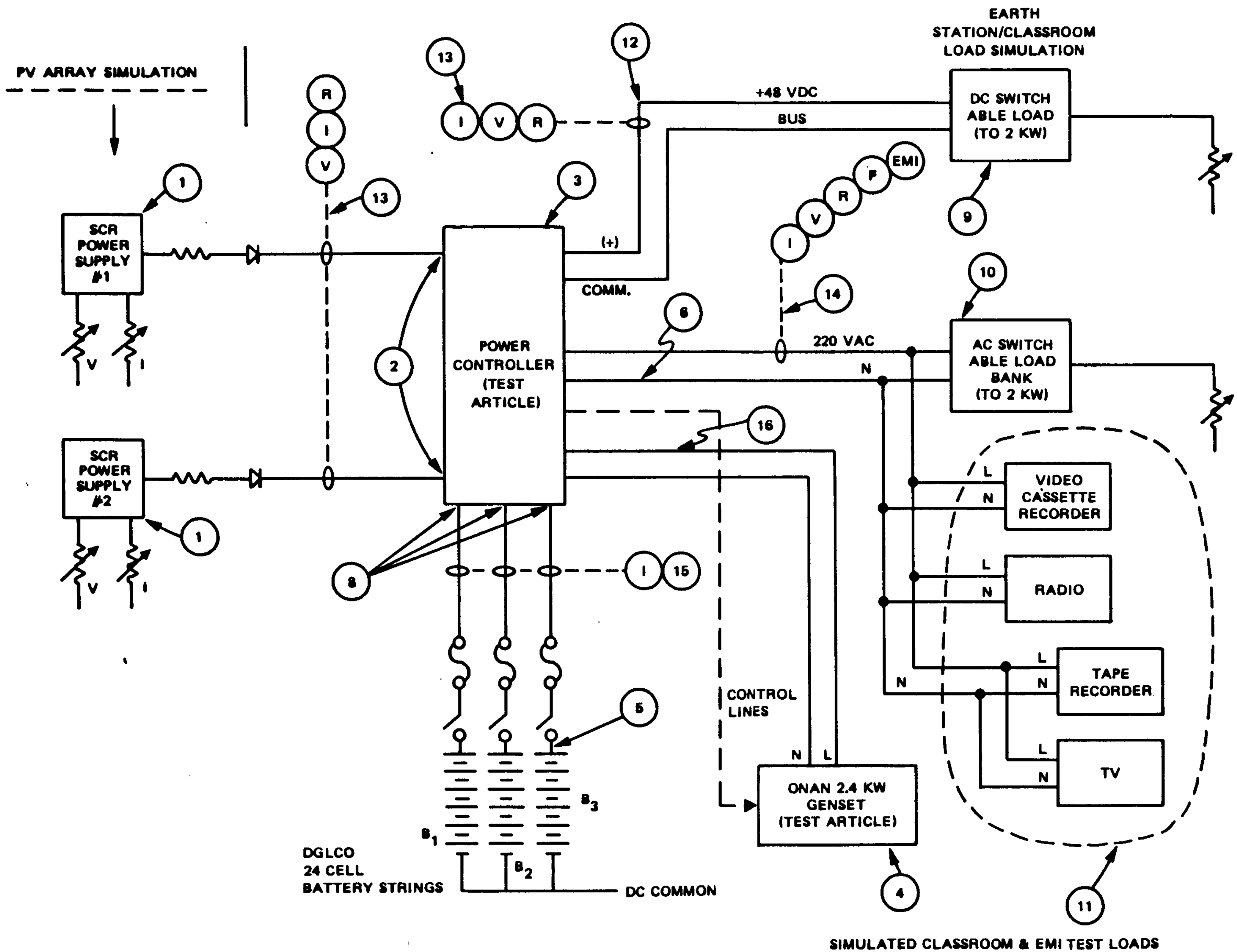


FIGURE 6-1 TEST INSTRUMENTATION & SET-UP FOR PROOF OF DESIGN TESTING

7.0 POWER SYSTEM INSTALLATION AT WAWATOBI, SOLAWGSI TANGGARA

The power system was installed at the selected site across the roadway from the Agricultural School in the outskirts of the village of Wawatobi, some 50 kilometers west of the coastal town of Kendari in Southeast Sulawesi of the Republic of Indonesia.

Installation commenced on May 11, 1985; final checkout was completed June 6, 1985. An overview of the installation activities is given in the paragraphs following. Pictorial data is included as appropriate.

7.1 LEADING PARTICULARS

The installation team on-site at Wawatobi consisted of the NASA Solar Project Office representative, the Hughes Field Engineer, and the Installation team from P.T. Elektrindo Nusantara, of Jakarta, Indonesia. The latter is a large telecommunications transmission systems engineering and manufacturing concern retained by Hughes to install the PV/Diesel Power System. This Elektrindo group independently installed the earth station under separate contract with AED (Academy for Educational Development).

7.2 SITE PREPARATION

The selected site is at the end of an unpaved road approximately 200 yard north of the main road to Wawatobi and Kendari. The actual installation complex is located in what was of originally a rice paddy; initial site preparation involved making a fill, creating a crushed rock (rip-rap) pad, of an elevation approximately one-half meter above the water table. It is estimated that about three to four meters of rip-rap had to be hauled in and compacted before stablization. The results of this civil work were excellent; the site drained well under torrential rainfall. The pad area, excluding later preparations for the classroom, was approximately forty by fifteen meters. This included the earth station site as well. The surface was compacted and graded smooth; the crushed rock was volcanic in origin, no chemical sterilants were needed. The required area for the PV installation and the security fence are shown in Drawing No. SEP-11507. Figures 7.2-1 is a photograph of the array field taken during wiring of the battery circuits. The boundary of the fill area with the original paddy maybe seen in the left front. Figure 7.2-2 is another view of the filled area, the original rice paddy, and the access road.

7.3 FOUNDATION INSTALLATION

Two types of foundations are installed at the PV systems site. An above grade concrete slab provides the foundation for the equipment shelters. In the original Hughes installation plan, the assembled metal troughs alone were to have provided an integral foundation for the entire array assembly.

The troughs were to have been installed directly on the fill. The long-term stability of the fill was however suspect because of the unknown nature of the underground soil structure. As an example a single workman was able to "sluice" a steel/copper ground rod to a depth of about three meters at a point only several meters beyond the periphery of the fill. At the time of equipment delivery, it was noted that three of the ballasted planter end-caps were missing

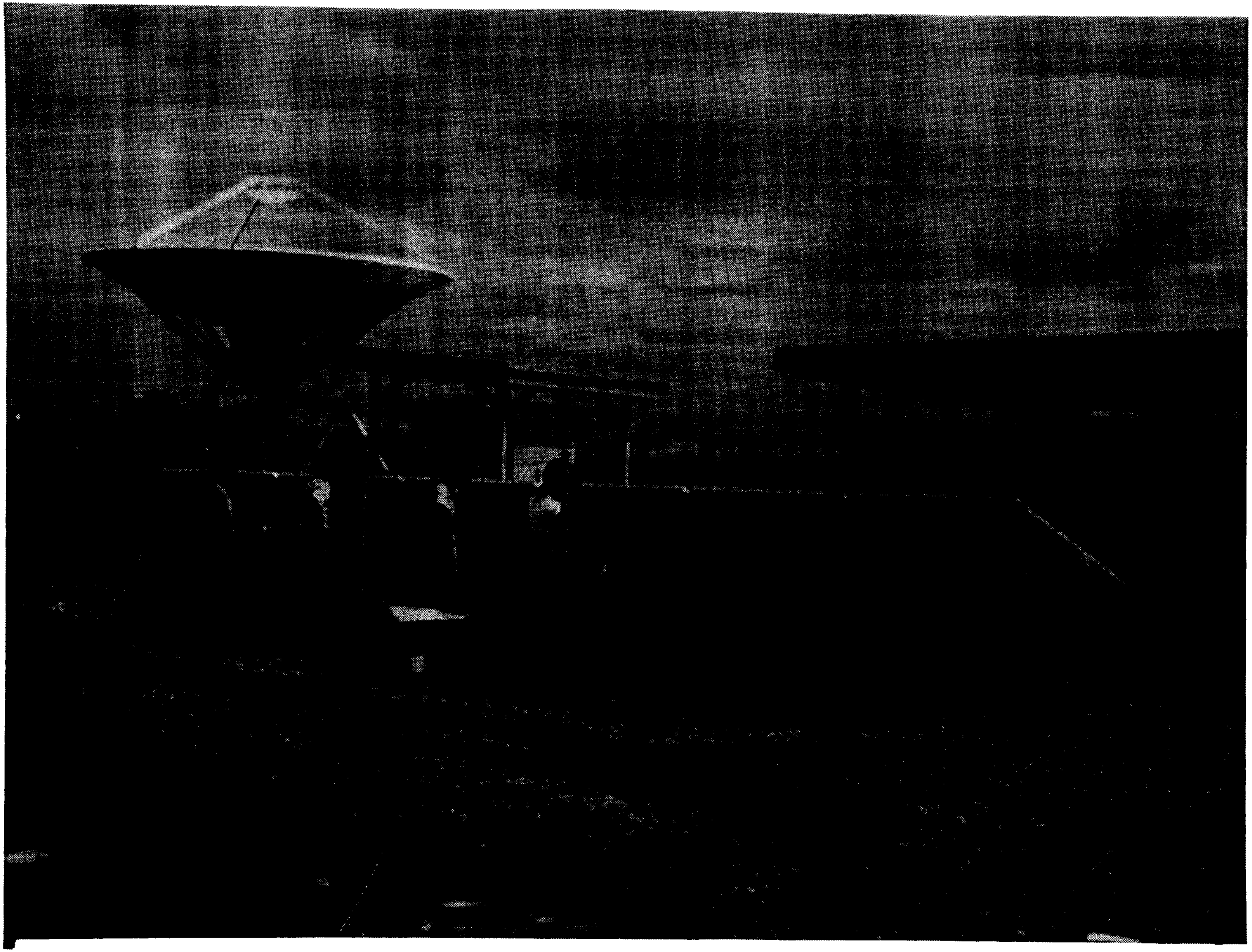


FIGURE 7.2-1 BOUNDARY OF FILLED SITE AREA SHOWING ORIGINAL RICE PADDY

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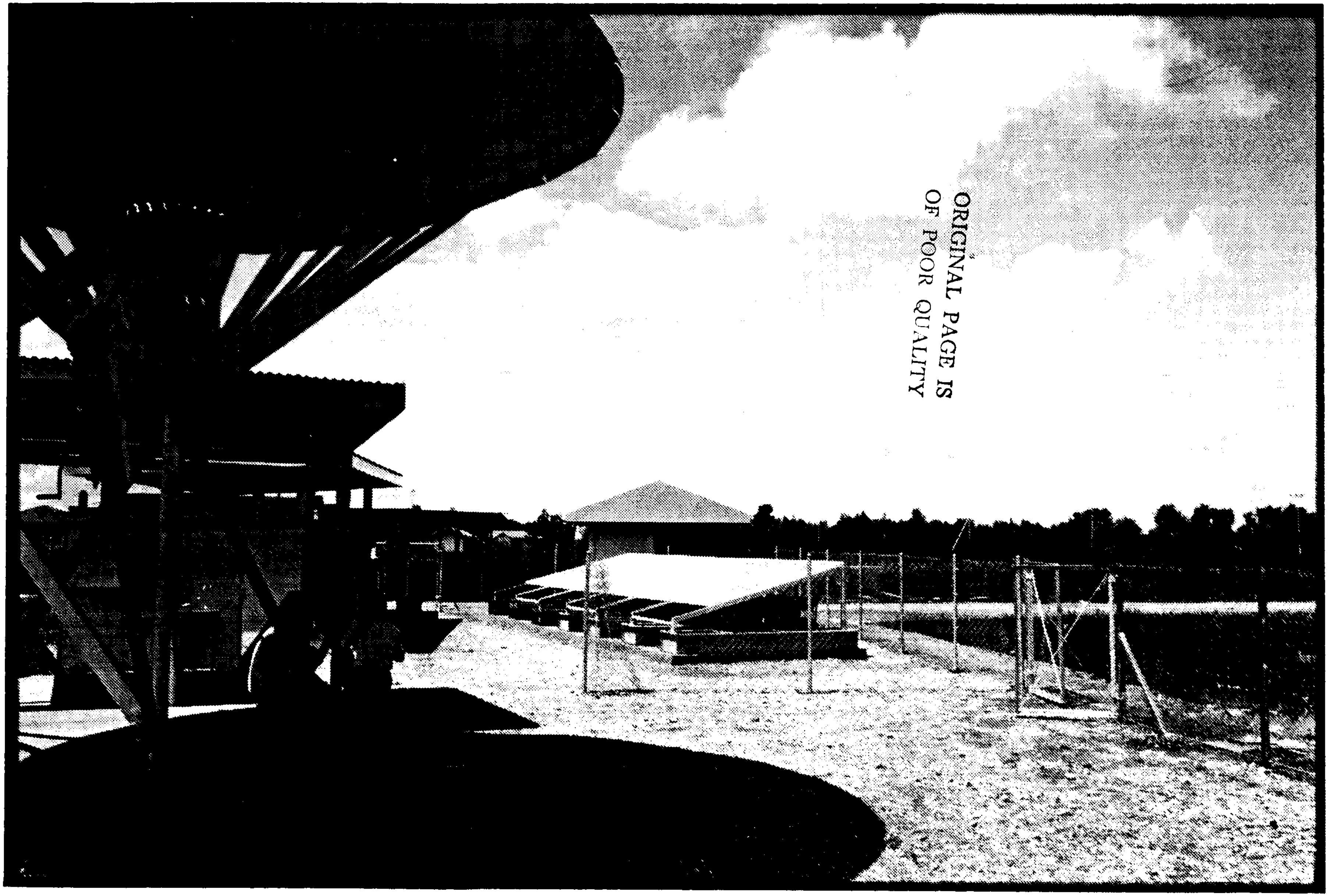

FIGURE 7.2-2 VIEW OF THE FILL AREA,THE ORIGINAL RICE PADDY, AND THE ACCESS ROAD

presumed lost in transit. Figure 7.3-1 shows this; replacement caps of local manufacture arrived shortly there after were installed as shown in Figure 7.3-2 following.

A 15 centimeter thick slab was therefore poured as a foundation for the contiguous panel assembly; the troughs were arranged in the proper orientation before erection of the panels was started. The availability of a slab could have of course made the ballasted troughs (planters) redundant. It was understood that at some later date this demonstration system might be moved to a second remote site and reinstalled. We elected to retain the planters so that they would never be separated from the balance of the assembly, and perforce the possibilty should the move need to be made. As a demonstration system, the net effect of the installation on a smooth, rectangular surface was excellent. The rationale for the apparent redundancy became quite understandable, once the requirement for ultimate portability was evident. See Figures 7.3-1 shows the demonstration installation; construction of the class room is proceeding in the background. The auditorium of the Agricultural School is shown in the far background.

Equipment Shelter Foundation

As shown in Figures 7.3-1 the equipment shelter slab was poured in an area of about four by seven meters square. The foundation was approximately 20 centimeters thick, providing total protection from flooding. Except for raised pad, the installation conformed to Drawing No. SEP 115-1.

Solar Panel Structures

Solar panel structural elements were assembled in accordance with Drawing No. SEP 11307. The trough components, Items 1, 2, 3, 4 on the reference drawing were assembled as shown, with the approved fasteners. The trough foundations were aligned on the concrete slab, which was orientated precisely in and east/west direction Drawing SEP-11501 provided the requisite guidance data. The alignment angles (Item 2) across the front stanchions, and the battery supports (Item 3) across the rear of the trough assembly (Item 1) tops were properly installed for the complete complement.

After completion of the mechanical assembly of the foundation, the troughs were ballasted with the local red rip-rap, hauled in from the quarry. The batteries were then installed upon their trough mounted racks, as shown in Drawing SEP-11389.

7.4 SOLAR PANEL INSTALLATION

The solar panel components and fasteners were assembled as depicted on Drawing No. SEP-11318. The photovoltaic modules (Item 1) were placed face down on a smooth assembly table; the left and right support channels: (Item 2 and 3) were then attached by using the fasteners (Items 4-7). The panels were then installed upon the trough foundation per Drawing No. SEP-11389, sheets one and two. The assembly method maybe seen in Figure 7.2-1 and 7.3-1 preceeding Figure 7.3-2 is that of the completed array field installation.

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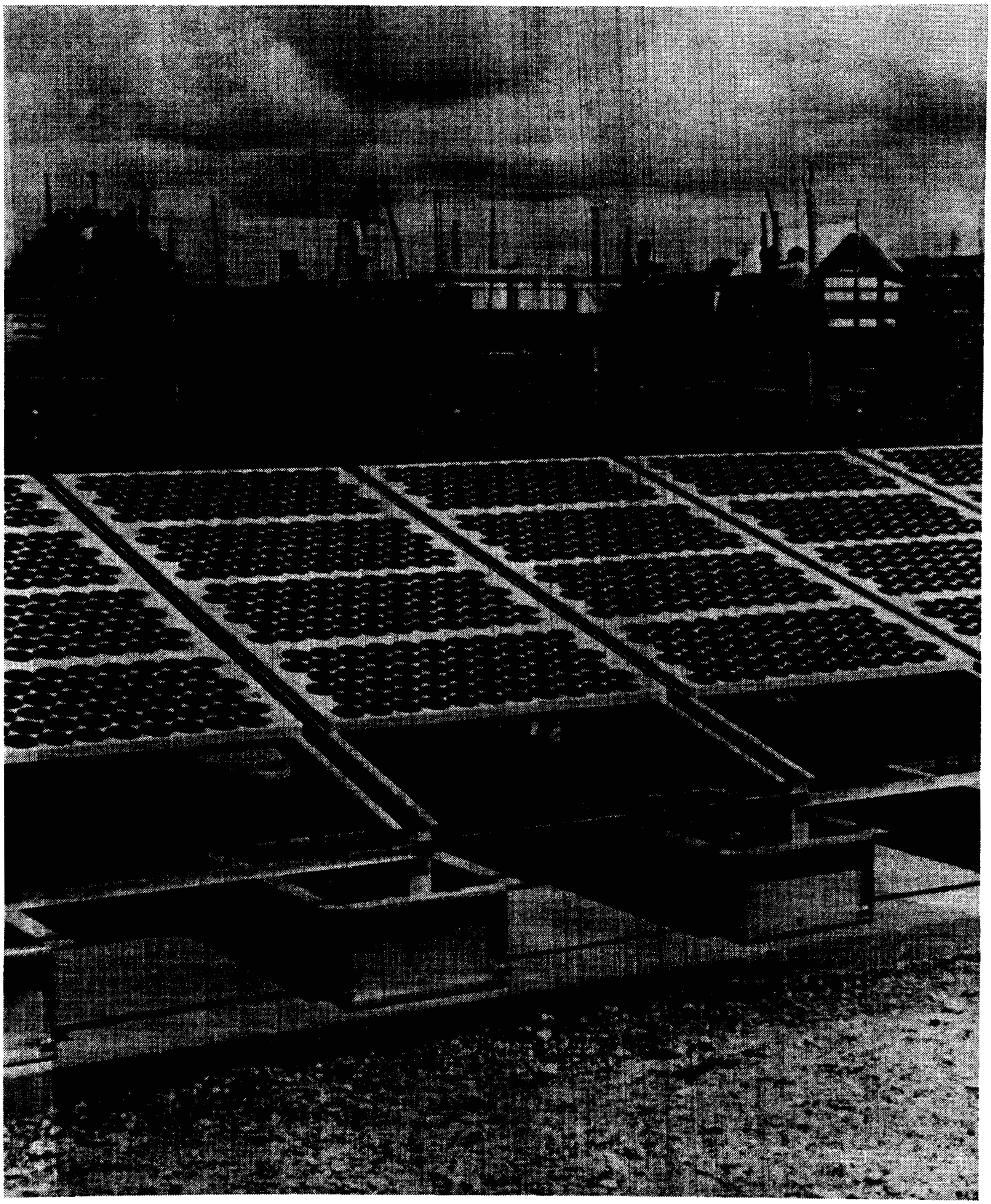

FIGURE 7.3-1 INSTALLATION OF BALLASTED PLANTERS ON PAD FOR DEMONSTRATION SET-UP (CLASSROOM UNDER CONSTRUCTION SHOWN IN BACKGROUND)

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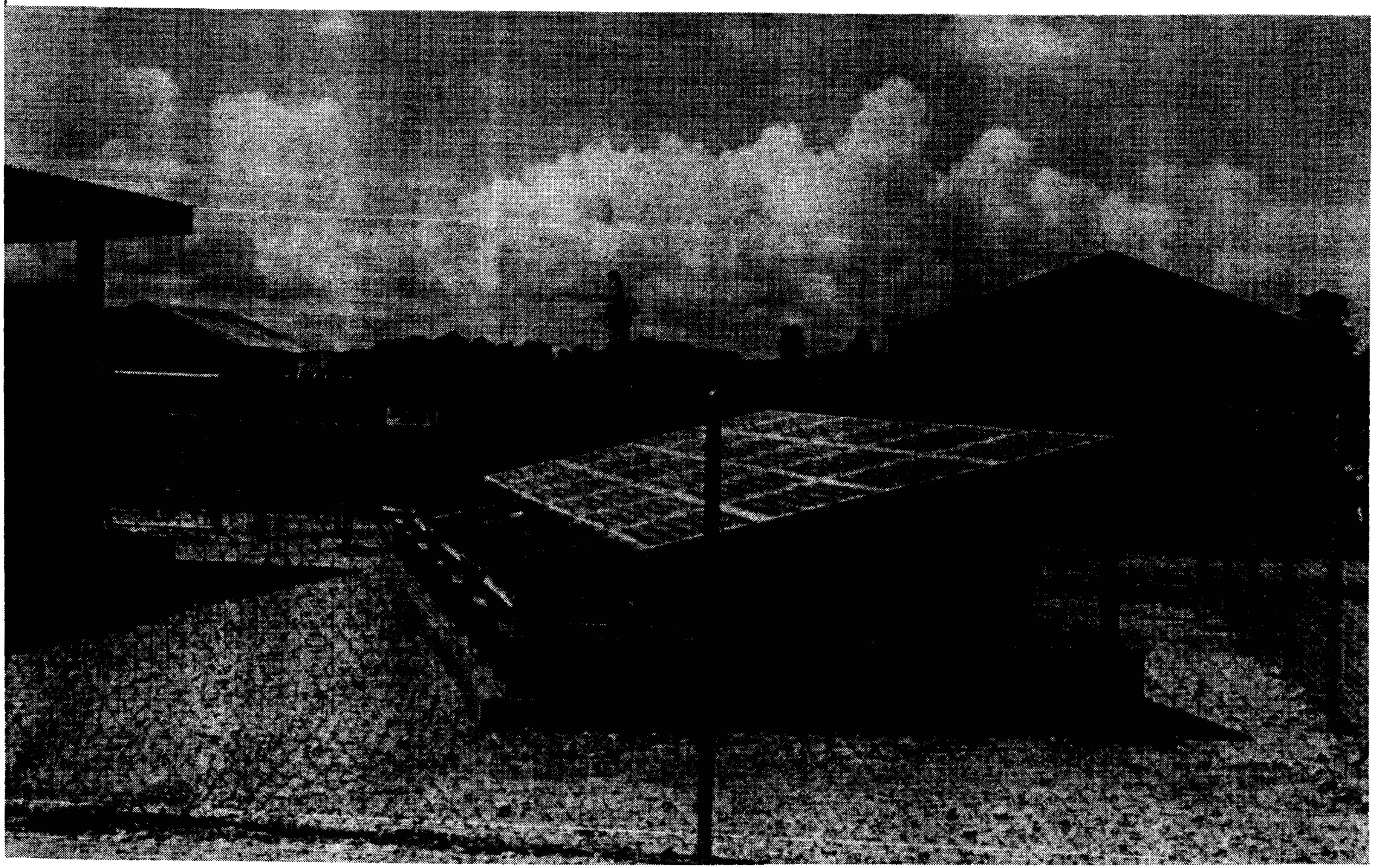


FIGURE 7.3-2 THE COMPLETED PV ARRAY FIELD INSTALLATION AT WAWATOBI

7.5 EQUIPMENT ENCLOSURE/SHELTER

A partitioned equipment shelter conforming the configuration and installation criteria given in Drawing No. SEP-11516 was constructed. It was built from local cinder block material and concrete, as depicted in the photographs, of Figures 7.5-1 following. The roof is metal sheathed; the structure is very rugged and survived gale force winds from local storms without incident.

7.6 EQUIPMENT INSTALLATION

The installation of the Power Controller units equipment bay may also be seen in the background of the photographs of figure 7.5-1 preceeding. The previously cast-in-place mounting studs were utilized. The GENSET installation included the fuel tanks, the muffler assemblly and penetration, the flapper valve and the support. The PV shelter lamps were installed, as were the alarm and interface boxes, and the safety switch enclosure. The security fence and lockable access gates were erected; the gate assemblies were fabricated on site by a local welder. Figure 7.5-1 also shows the batteries and safety switch assemblies (center and center left) the alarm box to the left of the power controller, as well as the power controller itself.

7.7 WIRING, INTERCONNECTION, AND HOOK-UP

Cables of the proper size were pulled through the conduits for all of the subsystems. The 800 watt Earth Station Inverter was substituted for the 500 watt device supplied with the Power Controller. The 500 watt inverter has been replaced by an 800 watt device. The 800 watt device was installed in the Power Controller Cabinet and wired in place. It is the only solid state AC source in the system.

The long AMP harnesses, Items 4, 5, and 6, on Drawing No. SEP-11501, were attached to the panels, and the leads pulled through the conduit to the Power Controller. They were then trimmed the desired length at the power controller cabinet and connected to the proper terminals as shown on Drawing No. SEP-11547. The standby generator cabling as also connected to the power controller terminals as shown on Drawing No. SEP-11547.

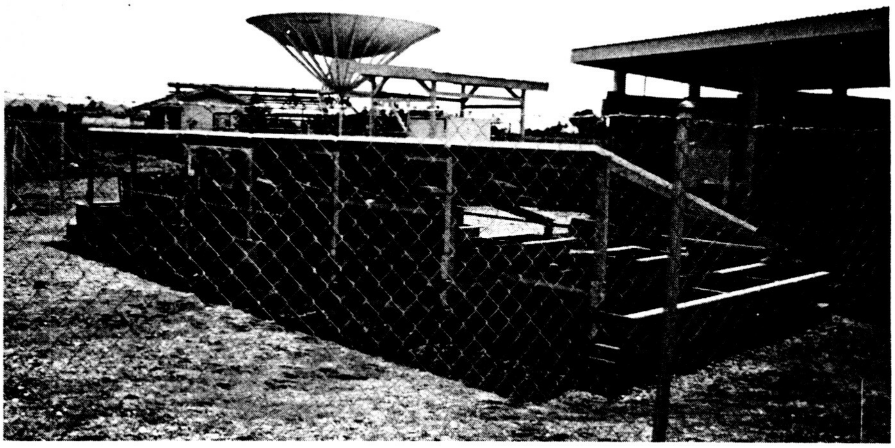
The PV panels were wired as shown on Drawing No. SEP-11501 with short AMP harnesses (Item No. 3).

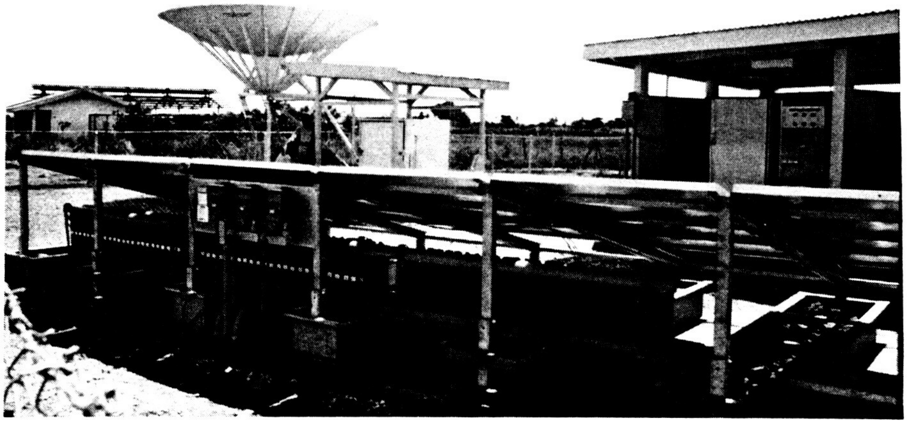
All remaining system cabling was wired in accordance with schematic Drawing No. SEP-11547. When connecting power cables and jumpers to the batteries, the panel support legs were unbolted from the panels, and the panels raised and propped up with lumber to facilitate easy and safe battery wiring and service.

The #6 AWG battery cables were also pulled, and attached to the battery safety fuse box per Drawings SEP-11498 and SEP-11547. For safety purposes, the battery jumpers, Item #2, were left unattached.

Continuity, "smoke" and megger tests were performed on all cabling. Terminations and interconnections were made before the application of any power for test purposes. A very rigorous inspection of the connections for accuracy was also made.

Exterior view, Power Controller Bay in Background





Open Power Controller Cabinet; viewed across the array

PV Equipment Shelter in right background

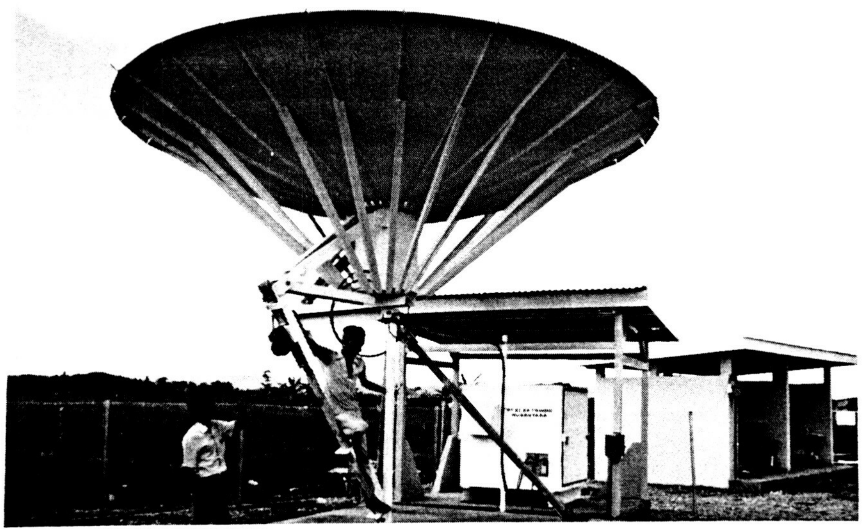


Figure 7.5-1. Views of the Installation Shelters and Equipment Bays

7.8 POWER SYSTEM ACTIVATION AND START-UP

The subsystems were carefully brought on line in a sequential manner prior to start of any functional testing at the systems level. The logic of the control system was modified to meet the requirements of the earth station with regard to uninterrupted (no-break) AC power. The diesel generator (GENSET) was serviced and satisfactorily brought on line. The inverter was activated and electronic AC power was supplied to the earth station. GENSET power was subsequently supplied to the Earth Station. The photovoltaic charging circuits and the battery-charger controller were checked-out and determined to be functionally correct. In short the entire power system was found to be fully operable and performing within specifications. The remaining tasks were therefore those of training and final system acceptance by the ultimate customer, Perumtel.

8.0 TRAINING OF PERUMTEL PERSONNEL

Approximately 15 members of the Perumtel technical staff attended the training sessions. Classes were convened in an Agricultural School classroom; the period of attendance was one week.

Personnel consisted principally of young Perumtel technical people, principally electrical engineers or operating personnel with advanced technical training. The four volumes of the Service and Operating instructions served as the principal instructional media. Course outlines were prepared and submitted to NASA for review and approval in advance of the conduct of the actual field training sessions. The course outline followed the progression implicit in the set of manuals.

The initial presentations covered principles of operation and functional description of the major subsystems, and their interfaces. Detailed discussions of system operation, control, and safety followed, with emphasis upon the major operating modes. The control and protective circuits were then explored in detail; question and answer sessions were held on both the detailed function as well as fault diagnosis and troubleshooting on each of the subsystems. The vulnerability of the battery and GENSET subsystems to improper usage and inadequate maintenance were highlighted.

It was originally planned to partition the class into two groups. One group was presumed to be operations oriented, the other would consist of advanced technical personnel more skilled in diagnostics and maintenance. The entire class turned out to be relatively uniformily qualified as well as somewhat modest in size. Instruction to the entire group with a single set of outlines, blackboard aids, and instructional material proved eminently satisfactory. Figure 8-1 shows one of the class sessions.

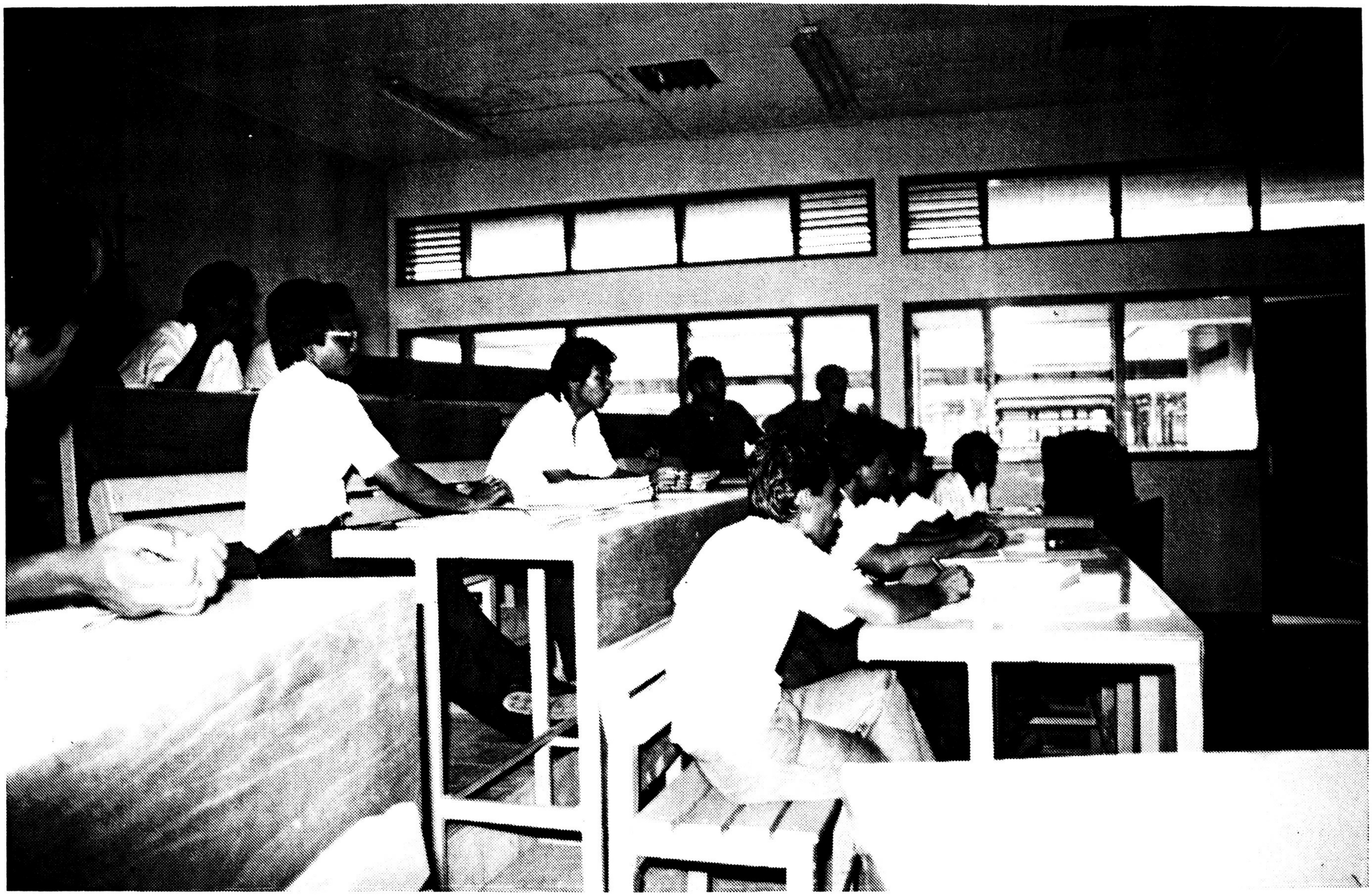


FIGURE 8-1 PERUMTEL ENGINEERS IN TYPICAL CLASSROOM TRAINING SESSION

9.0 SYSTEM ACCEPTANCE AND COMMISSIONING

Final testing began in the last week of May 1985, and was satisfactorily completed on June 2, 1985. This span included the successful training of Perumtel personnel, through the medium of both the formal classroom and hands-on field instruction. The complete hybrid system was bought-off on 3 June 1984.

Prior to functional testing a walk-through review as well as inspection of both hardware and documentation was conducted. This included all aspects of provisioning, as well as the 1986 plans for unscheduled maintenance.

Final Acceptance Testing involved functional testing of system performance to specification. Inspection had been completed; a condensed buy-off procedure was promulgated jointly by NASA and Perumtel, and accepted by Hughes. This final version, as executed on 3 June, 1985, is included as Appendix B.

Several discrepancies were identified following the commissioning tests. These discrepancies principally resulted from minor parts failure, and the malfunction of the spare inverter. A string of batteries had of course already been destroyed by up-ending during shipment (or storage); these were necessarily included on the list. Paragraph 9.1 following is an exert from the Hughes letter of 25 June summarizing the situation. As of this submittal appropriate corrective action has been taken on essentially all the problems.

Conditional acceptance of the PV Power System, installed at Wawatobi, Indonesia, was received by NASA from Perumtel. Training was fully accepted; a copy of the Perumtel signed document is included in this report.

9.1 SUMMARY OF EVENTS/ACTION ITEMS

During installation and test, a number of events occurred and were recorded by Mr. N. A. Marshall, our onsite Hughes installation supervisor. They are:

9.1.1 The 500 watt inverter was inoperable, and the unit remains at the site in this condition.

9.1.2 Several batteries were unusable due to being turned over during transshipment from port of entry, Jakarta, to final site destination, Wawatobi.

9.1.3 Control relays (2 each), and a ground fault interrupter, parts failed during checkout.

9.1.4 A new, additional, small, DC Power Supply (DCPS), associated circuitry, and circuit changes to accommodate the DCPS were added to the Power Controller Cabinet.

9.1.5 The 800 watt inverter from the Earth Station was relocated to the Power Controller Cabinet, replacing the 500 watt inverter; a new hook-up was made for this field modification.

9.1.6 The battery meter on the power control panel reads incorrectly; this requires investigation.

9.1.7 The customer has submitted a list of modifications and improvements that they wished to have incorporated; the subject list was transmitted to NASA.

9.2 INTERIM RECOMMENDATIONS

For the items above and in the same sequence, the following are recommended:

9.2.1 Replace the inoperable 500 watt inverter with a new 800 watt inverter to be used as a spare for the one currently installed. (Completed)

9.2.2 Replace the damaged batteries. (Completed)

9.2.3 Replace faulted relays and contactors with new units. (Completed)

9.2.4 Purchase a second, small, power supply (DCPS) and send to the site as a spare. (Completed)

9.2.5 The 800 watt inverter is discussed under Items 9.1.5, and 9.2.1 preceeding. (Completed)

9.2.6 Replace the battery meter and shunt. (Completed)

9.2.7 NASA will be asked by Perumtel to review the Perumtel requested additional tasks referred to in Paragraph 9.1.7.

APPENDIX A

PROOF-OF-DESIGN TESTS

PROOF-OF-DESIGN (P.O.D.) TEST PLAN

FOR

SATELLITE EARTH TERMINAL

P.V. POWER SYSTEM, INDONESIA

SEP: 11622

DATE: 9-5-84

HUGHES

PREP BY [signature]

APPROVED ____________

NASA LeREC

APPROVED ____________

DATE ____________

APPENDIX A

Proof-of-Design Acceptance Tests on the Remote Earth Terminal, Indonesia

OVERVIEW

A Proof-of-Design (POD) Aceptance Test Plan, Hughes document SEP 11624, was submitted to NASA early in September 1984, approved and returned to Hughes.

At the factory system test site, functional acceptance testing of PV module strings at the assembled (or wired) level was considered excessively costly and marginally contributory to evaluation of functional adequacy. Damage and a possible warranty violation also could be involved in the unpacking, assembling and packaging of batteries as well as PV modules.

The pivotal element of the above approved plan for POD testing was that of precisely simulating the dynamic characteristics of both the PV power source and the battery subsystem. The major test articles therefore became the central power controller, the diesel GENSET, the peripheral instrumentation and the integrated control system and sensors. This test configuration is depicted in the block diagram of the test bay. A POD Acceptance Test Plan based upon the above considerations was submitted to NASA on 6 September, 1984 and approved and returned by NASA shortly thereafter.

The test set up and the deliverable hardware were installed and hooked-up during the week of 19 September, 1984. System checkout was started; wiring errors in the power circucits temporarily interrupted the testing; it was however resumed on the 26th of September. The final testing was witnessed by Mr. Ratajczak of NASA, and the bulk of the tests described were successfully completed.

The inverter was tested toward the end of the routine. Unfortunately, a previously undiscovered vendorfactory error in the generator grounding system produced an AC ground fault in the inverter bridges; the tests had to be stopped and the inverter was temporarily returned to the factory for the necessary repairs. Tests were successfully completed by 3 October; after several days additional burn-in, the subsystems were disconnected, packed, and prepared for shipment on 13 October. The changes in schedule, as well as the actual test procedures and results were provisionally approved by the NASA representative at Long Beach.

TABLE OF CONTENTS

1.0 GENERAL INFORMATION

1.1 SCOPE OF THE P.O.D. TEST PLAN.

Per Para 2.3 of Exhibit A (RFP 1409503):

> "A Proof-of-Design (P.O.D.) Test is required to determine whether or not the individual subsystems and major assemblies meet the manufacturers' specifications within the limits of intended use, and, whether or not they perform as designed so (sic) as to produce the required integrated system performance."

Hughes is required to design and conduct subject verification tests. Our additional responsibility is to specify and ensure the conduct of suitable acceptance and qualification tests on other BOS elements, principally the PV modules, the batteries and the GENSET. POD Testing at the system level is herein described. Other factory acceptance and subsystem testing is referenced as appropriate.

1.2 DELIVERABLES TO BE EVALUATED IN THE P.O.D. TEST

The Test Set-up and its electrical configuration is described in Section 2.0, per previous agreement with NASA, two deliverables were necessarily deleted from the test article complement, and functionally replicated. These substitutions accrue the following signal advantages in both cost effectivity and reliability:

a. The battery complement, after being subjected to full factory acceptance testing at the manufacturer, C&D, can be shipped directly overseas in their original factory shipping crates. The risk of local repackaging damage (or errors) is precluded; the test use of an equivalent PgCa facility battery of lower capacity will in no manner compromise the test results.

b. Assembling of the structures, PV modules and panels into the installed configurations proves very little; The power generating properties of the PV modules will have been fully characterized by factory qualification/acceptance tests; the structures are known, workable kits. Further, this costly exercise exposes the modules to additional handling risks; these can be easily avoided by synthesizing the electrical characteristics of the array with appropriate regulated power supplies and impedances.

The balance of the deliverable subsystems and assemblies involved as test articles are as follows:

a) The Power Controller
b) The Alarm Assembly
c) The GENSET
d) The Instrumentation Cabinet (and sensors)

As will be shown, the test elements will permit full functional verification at both the system and subsystem level.

1.3 TEST OF BALANCE OF DELIVERABLES

1.3.1 PV Modules

The photovoltaic modules will be factory tested in accordance with the requirements of the module procurement specification, SEP 11396. This data will be made available to NASA.

1.3.2 Batteries

Certified copies of the factory acceptance tests on the C&D batteries will be made available to NASA.

1.3.3 GENSET

Copies of factory run-in test data on the GENSET will be made available.

1.3.4 Other

As appropriate, CERTs and calibration data on system instrumentation and other significant procurements will be available for inspection.

1.4 INSPECTION OF SYSTEM DESIGN CONFIGURATION

The detailed specifications of Appendix A of RFP 3-409503, (Contract NAS3-23862) include a number of ancillary requirements. The majority of these items are retained on a "need to include" basis. As such, their acceptability requires a configuration inspection and not a demonstration of functional adequacy. This test plan is advanced upon the premise that the design configuration has been inspected earlier and both the design package and the hardware found to be compliant.

2.0 TEST SET-UP

2.1 SUMMARY DESCRIPTIONS

Figure 2-1 depicts the P.O.D. the power flow and the facility instrumentation. The diagnostic interfaces and essential intra system control lines are also shown.

The output of the PV array elements will be synthesized by employing two regulated SCR phase angle controlled power supplies, each delivering the simulated output to one of the two regulating channels of the bi-level series regulator.

The system batteries will be replicated by employing three 48 Vdc parallel strings of DELCO 2000 batteries; each of the strings consists of four series 12 volt batteries, or 24 series lead calcium cells per string. The ampere hour capacity of these cells is approximately 40% of that of the deliverable C&D units. Both are moderate discharge devices; the disparity in A-H capacity is not detrimental to test validity.

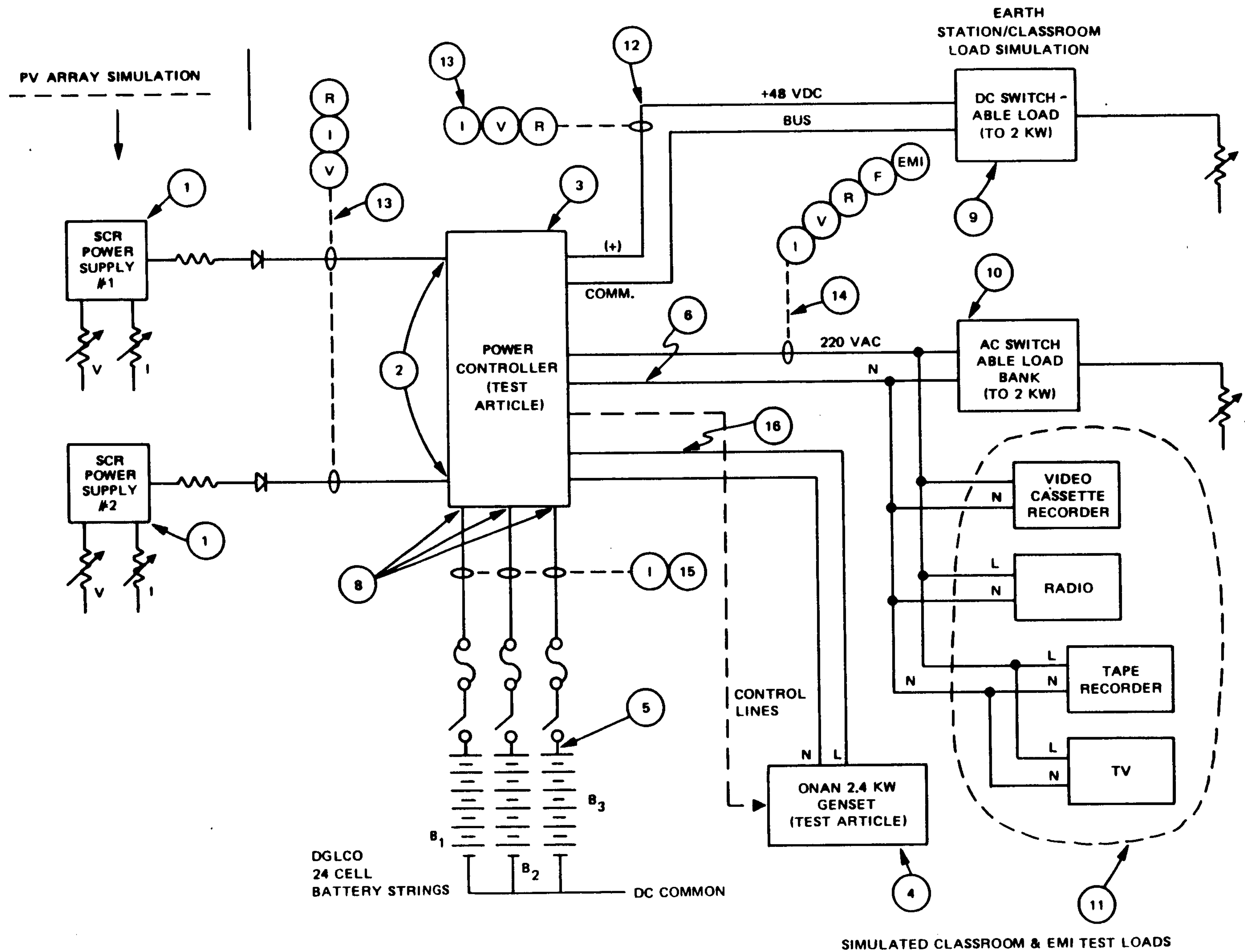


FIGURE 2–1. TEST INSTRUMENTATION & SET–UP FOR PROOF OF DESIGN TESTING

The earth station DC load will be simulated by switchable load banks capable of dissipating in excess of 2 kW in free air. The actual loads are assumed to be resistive; the low output impedance of the station battery, however, permits almost any conceivable type of DC load (within ratings) to be started and supported.

The AC loads are substantially resistive, except for TR/VCR/VC drives. Adjustable resistive loads will be satisfactory.

2.2 MAJOR SUPPORT POWER APPARATUS

The principal items of power apparatus used in the test set-up are the Computer Measurements Power Supplies used to replicate the array outputs. The current limits of each of these supplies will be set at the summed short circuit limit of three source-circuits, an Isc of about 15-16 Adc. The voltage limits will be set to yield an open circuit voltage of 71-73 Vdc, which approximates the Voc of four series modules. Fine tuning of the current and voltage controls in combination with the fixed 1000 milliohm resistance should provide all of the essential simulation characteristics. Crowbarring may be done with no risk of damage.

2.3 TEST INSTRUMENTATION

The major items of test instrumentation will be the Gould Model 222 Recorders. These precision analog devices have sufficient chart paper (275 feet) for many hours of continuous recording. They operate on DC voltage and will cover the full parametric ranges of AC and DC voltages (1 millivolt/div to 10 volts/div) with a RSS accuracy of better than 1/2%. Four event markers are available, two per recorder. These will be used to correlate the occurance of critical switching events with the analog levels at that time then extant. Common mode problems will not be present due to the DC supply isolation.

Supplemental portable test instrumentation, hand-held DMMs, Hall probes, and possibly scopes will be used from time-to-time at various points on an as required basis.

3.0 POWER CONTROL & ACTIVATION CHECKOUT

This group of tests verifies:

a) that the system can be safely and smoothly brought on-line.

b) that all mode controls, test and switching functions are operating to specification and the system responds properly to both manual and automatic commands.

c) that all protective, alarm, and instrumentation functions are properly operating.

3.1 INITIAL SYSTEM ACTIVATION

With all circuit breakers open, mode control switches in "AUTO" and the battery connected, activate the control system by operation of the emergency power pushbutton. The application of central power will energize the green "GO" displays for Channels "A" and "B", signifying readiness for coupling the loads and the alternative power sources.

DID THIS ACTIVATION OCCUR? __✓__ YES; _____ NO; ACCEPTED _______

3.2 C/O MODE CONTROLS AND DISPLAYS

With the mode control switches initially in the "AUTO" position, progressively place each function into the "MANUAL DISCONNECT" and "BYPASS" mode. The corresponding status lights should activate or extinguish.

DID THIS FUNCTION OCCUR? __✓__ YES; _____ NO; ACCEPTED _______

3.3 TEST FUNCTIONS

Sequentially place each test function in the "HI" or "LO" mode. This action will manually override the corresponding display and control mode when momentarily placed in the opposite "HI" or "LO" states. No change will occur if the function is <u>already</u> in the particular test status selected. Repeat as required.

DO TEST FUNCTIONS OPERATE PROPERLY? __✓__ YES; _____ NO; ACCEPTED _______

3.4 POWER SWITCHES AND INTERRUPTORS

Open the six circuit breakers breakers (CB1, CB2, CB3, CB4, CBA, CBB); this will interdict all PV power sources to the loads, the DC power to the inverter and the Earth Station 48 Vdc bus. Move the "GENSET DEMAND" mode switch to "MANUAL DISCONNECT", this will complete the termination of all power flow, "IN" and "OUT" of the power controller. Now apply representative loads, typically 10 Adc and 1 A (rms) respectively, to the corresponding system output feeders. Place the AC source select on the internal to the "INVERTER" mode. as the particular function is reactivated.

WERE THE SWITCH CLOSURES OBSERVED TO BE IN ACCORDANCE WITH THE DESIGN? __✓__ YES; ____ NO; ACCEPTED ______

3.5 C/O OF GENSET CONTROL FUNCTION

With PV array inputs switched off and UV/OV in "AUTO" mode, go to "BYPASS" on GENSET DEMAND. The generator should crank and start. Now return that function to automatic mode. Switch the EOC test button to the "HI" state; the GENSET should go off. Now hold the GENSET Test button in the "LO" state; the GENSET should restart.

DID THESE CONTROLS PERFORM PROPERLY? __✓__ YES; ____ NO; ACCEPTED ____

3.6 OPERABILITY OF BUILT-IN (SYSTEM) INSTRUMENTATION

a) The operability of the monitoring instruments and other diagnostics should be checked. Place all control functions to the automatic mode. The batteries must be discharged to approximately 85%.

b) A nominal DC load of 10 Adc is applied.

c) A nominal AC load of 1 A(rms) @ 230 Vac is applied.

d) Close the PV array channel "A" and "B" circuit breakers, observe PV charging current.

e) Compare the observed PV amps, DC load amps, and battery amps (charge or discharge) with the current channel levels of the recorder.

f) Repeat d) and e) for AC load amps, AC volts, DC volts.

g) Compare the various recorded AH readings with average current readings over a one hour period (amps x time); this verifies the operability of the readouts.

h) Repeat steps d) and g) substituting the activated GENSET for the PV array. The PV and the GENSET DEMAND must be switched to "BYPASS" for this test. A moderately discharged battery (80 - 85% FC) is required for this test.

DOES THE INSTRUMENTATION PERFORM PROPERLY?
__✓__ YES; ____ NO; ACCEPTED ______

3.7 CROWBAR FUNCTIONS

This test is required only if the crowbar functions have not been previously evaluated under para 3.3 preceeding. Place the momentary action test switch labeled "CROWBAR" in the "HI" position; a trip should occur. The red "CROWBAR" light should go on, signalling a closure. The crowbar contactor will release with as the reset button when depressed.

DOES THE CROWBAR OPERATE PROPERLY? _____YES; _____NO; ACCEPTED _______

3.8 OPERABILITY OF ALARMS AND WARNING INDICATORS

Verify the operability of alarms and warning indicators. The crowbar and UV/OV failure warnings can all be simulated from the test panel by switching to the responsive test position. GENSET START FAILURE can be tested by deliberately introducing a staged fuel shut off in the GENSET. The external aural and visual warning devices are energized by an undervoltage fault and/or GENSET "FAILURE TO START" signal.

DO ALL ALARMS AND WARNINGS PERFORM AS DESIGNED?
_____YES; _____NO; ACCEPTED _______

3.9 INVERTER OPERABILITY

With the "GENSET DEMAND" control in the "MANUAL DISCONNECT" mode, turn the Inverter switch "ON" and place the AC select switch in the "INVERTER" position. The AC loads should remain the same as previously stated, approximately 1 A_{rms} at 230 Vac, 50 Hz.

The presence of AC power may be observed on the POP panel meters; current flow will take place when the AC interruptor CB-3 is closed. The voltage under load should be 230 Vac $\pm 5\%$; the frequency should be 50 Hz $\pm 1\%$.

IS THE INVERTER FUNCTIONING PROPERLY? _____YES; _____NO; ACCEPTED _____

3.10 AC POWER TRANSFER FUNCTIONS

Turn the Inverter switch to "ON". Return the GENSET DEMAND SWITCH the "BYPASS" (ON) mode; the GENSET should crank, start and deliver power. Place the AC Source Select Switch in the "AUTO" position; now place the GENSET control in the "AUTO" mode and hold the EOC test switch in "HIGH". The GENSET should turn off, returning the classroom bus to Inverter power. Observe Inverter power quality.

Now place Source Select Switch in "Inverter" position. No change should be observed. Restart GENSET as previously outlined. Now move Source Select Switch to "GENSET". A slight interruption will occur at transfer. Observe differences in power quality, if any.

DID THE MANUAL TRANSFER OF THE AC POWER SOURCES OCCUR AS SPECIFIED?
_____YES; _____NO; ACCEPTED _______

4.Ø VERIFICATION OF SYSTEM POWER GENERATION AND CONTROL CAPABILITIES

4.1 PURPOSE

The purpose of this test is to verify compliance of the design with specific requirements of the governing contract specifications abstracted as follows:

PARA 1.1

- Normal mode of operation shall be PV . . .
- GENSET charges the battery thru the charger during insolation shortfall or failure of array to deliver the requisite power.
- GENSET available at all times to power load directly in the event of battery or other BOS element failure.

and

PARA 4.Ø (1): "provides system voltage control. . ."
PARA 4.1 SYSTEM VOLTAGE CONTROL: " . . . provide operational voltage control within manufacturers stated voltage limits (float and charge voltage control); establish proper limits for other subsystems.

4.2 STAND-ALONE PHOTOVOLTAIC OPERATION

4.2.1 PRELIMINARY

This test is designed to verify the capability of the system to safely and reliably operate in the stand-alone photovoltaic mode. Preconditions include the following:

- A fully operable power controller, with both PV charge control channels properly calibrated.
- Station battery strings at least charged to 85%.
- Calibrated System Instrumentation and Power Apparatus.

Each PV simulation power supply should be set to deliver approximately 15 Adc at 6Ø Vdc per previous instructions. The Voc should be about 72 Vdc. Two of the three battery strings (four series Delco 2000 batteries) 24 series cells at 2 VPC or 48 Vdc nominal. The dummy load should be switched off during this initial phase.

4.2.2 GENERAL PROCEDURE

The approximate C/5 recharge rate should result in a terminal battery potential of less than 2.3Ø VPC if the two battery strings have been (two of three strings) discharged to 8Ø% of 8 hr. capacity. For the 2ØØ AH parallel strings, the 3Ø Adc charge rate should restore the electrolyte to near 13ØØ within several hours.

Connect up the Gould 222 Recorders as directed by the test set-up drawing, Figure 2.1. Activate both analog and event channels of the two Gould 222 Recorders, using chart speeds of 5 mm per second; this will result in the data occupying a relatively short chart paper length. The event channels on the #2 Gould Recorder track the states of the Channel "A" (float charge) and the Channel "B" (charge tape) comparators. The bus voltage corresponding to the particular state ("ON/CHARGE" OR "OFF/STANDBY") of each channel may be read directly off of the precision analog trace. The simulated PV current is recorded on the second analog trace; the four data inputs will characterize the performance of the system in the normal PV mode.

Start a charge cycle in the absence of a diversionary load. Manually activate the load bank after float channel turn-off. This will yield a rapid charge/discharge sequence and forces the system through the charge voltage regulation cycle. Following completion of this initial phase, full automatic operation without manual intervention for load switching shall be instituted. Depending upon the time available, several other combinations of simulated PV input, and load demand can be later set up by adjusting the power supplies and the value of the dummy loads, and shedding one of the two battery strings.

DOES THE SYSTEM PERFORM AS REQUIRED IN THE AUTOMATIC PV STANDALONE MODE?
___✓___ YES; ______NO; ACCEPTED _______

4.3 BACK-UP POWER FROM GENSET

PREPARATORY

The system is presumed to have successfully operated and met the essential performance requirements of PARA 4.2 preceeding. It is now necessary to determine the ability of the GENSET to both manually and automatically take over the battery charging and load support function. The following test sequence applies.

a) The "GENSET DEMAND" mode control switch is returned to "AUTO".

b) It will be verified from calibration records that the "GENSET DEMAND" channel will go "HI" (latch the GENSET Start line "ON") when the bus voltage sags to 1.95 Vpc (46.8 Vdc), and that the EOC channel releases the GENSET Start line when the bus potential rises to 2.33 Vpc (55.92 Vdc).

c) This transfer test is conducted under the premise that only problem in operating as a standalone PV system is insufficient solar insolation to autonomously support the station load; otherwise the array is completely functional.

d) The built-in battery charger will have been set at 60 Vdc and current limited at 20 Adc. Slightly over 2 hours operation will restore the charge to the two 100 AH strings that have been discharged to 80%.

4.3.1 INITIAL OPERATIONS

Manually intervene, coupling on the dummy loads after automatic GENSET shutdown at "end-of-charge". After automatic GENSET START UP the dummy loads should be shed to divert all available charging GENSET power to the batteries, thus compressing the test cycle. For the purpose of this test, the DC dummy load should demand 10 Adc @ 60 Vdc; the 230 Vac AC load should be set at 1 A $_{(rms)}$. The strip charge recorder should be activated with the DC charger and load currents recorded on Gould #2, along the events depicting the state changes in the Load Demand Channel comparator, and the EOC Channel. Proceed on this accelerated test routine, alternating between manual pick-up and release of the dummy load at the proper time in the cycle, Record results.

4.3.2 ON-GOING GENERAL PROCEDURES

Adjust the value of the dummy load until a convenient cycle length is established; both the inverter and the DC earth station load can be increased by about 35% to accelerate recycling. During this cycle note the status lights depicting the several sources of power, thus ensuring the transfer has been made. The float cycle/charge taper characteristics of the PV charging subsystem will have been well documented at this point.

Shift Analog Channel #1 (DC PV load amps) of Gould 222 #1 to AC volts (500 Vac pk scale) to measure the magnitude of the AC power output. This will provide a direct record of the output AC power magnitude and its' stability as it is supplied by either source.

4.3.3 MANUAL OPERATION

Repeat 4.3.1 and 4.3.2 by going to the manual operating mode at predetermined times in the charge/discharge sequence.

DOES THE OPERATION OF THE GENSET IN TANDEM BACK-UP WITH THE STAND-ALONE PV SYSTEM (AUTOMATIC AND MANUAL TRANSFER MODE) MEET STATED REQUIREMENTS OF 4.3.1, 4.3.2, 4.3.3? ____ YES; ____ NO; ACCEPTED ______

4.4 STAND-ALONE GENSET OPERATION

4.4.1 PURPOSE

The purpose of this test is to verify that the GENSET can provide power directly to the earth station in the event of a catastrophic failure of the battery or an inverter. This is the requirement of PARA 1-1, "Systems Operation", of the governing specification, which further stipulates that the GENSET must be directly available to preclude interruption of power to the Earth station.

This emergency state condition of stand-alone operation on GENSET is predicated upon the following:

a) The control circuits interacting with the GENSET are fully operable

b) The integral AC/DC Power Supply converting GENSET 230 Vac 50 Hz power to 60 Vdc is fully functional

4.4.2 GENERAL PROCEDURE

a) Shut the system down completely, including tripping the emergency "SHUTDOWN" pushbutton. This latter action shuts off control power.

b) Ensure both PSP Channels "A" and "B" circuit breakers are open. Place Mode Control switches "CH A" and "CH B" in MANUAL DISCONNECT mode.

c) With the loads disconnected, place the AC Source Select Switch in the "GENSET OPERABLE" mode.

d) Prior to closing the load control contactor, make sure the following dummy loads have been established:

d-1: Earth Station 48-50 Vdc 10-15 Adc (900 watts DC max.)
d-2: Classroom load: 230 VAC @ 2 A (RMS) (500 watts AC max.)
d-3: Supplemental AC maintenance load 230 Vac at 4 ARMS (900 watts AC max.)

e) Now place the GENSET mode control switch in the "BYPASS" (ON) mode. The GENSET should crank, supplying AC power (via the AC/DCS) indirectly to the Earth station DC load. Activate the Control Power pushbutton switch to restore power to the control DC bus and permit all protective circuits to operate. This latter step permits the load control contactors to be closed.

With the activation of the load control contactors and closure of the load circuits the AC classroom, the DC Earth station and the maintenance bus will now be activated and the power interface terminal boards in the IPB (Interface Panel Board) should be energized.

f) Once the power has been verified to be in specification, continuous, and not producing any unexpected temperature rises, the tests may be terminated.

DID THE GENSET SUPPORT THE EARTH STATION LOAD ON IN AN ACCEPTABLE MANNER UNDER THE CONDITIONS SPECIFIED? ✓ YES; _____ NO; ACCEPTED ______

5.0 VERIFICATION OF FAULT PROTECTION AND FAIL-SAFE FUNCTIONS

5.1 PURPOSE

The purpose of this test routine is as follows:

5.1.1 Ensure that both the primary (photovoltaic) power system and the back-up system (GENSET) will not unfavorably interact in the event of a catastrophic failure of either. (IMPLICIT IN PARA 1.1)

5.1.2 Ascertain that provisions have been made for positive control of system voltages to within safe operational limits specified by the manufacturer (all charging conditions, including initial, taper, float; PARA 4.1).

5.1.3 Ensure that the system will shut down or otherwise automatically enter a fail-safe standby mode in the event of out-of-tolerance over and under-voltage conditions on the main system bus (PARA 4.2 (a)).

5.1.4 Prevent battery depths-of-discharge greater than those specified by design (PARA 4.3).

5.1.5 That the system, the load and operating personnel are protected against potentially damaging out-of-limit battery and load currents.

5.1.6 To verify that the DC Ground fault relaying system operates as specified.

5.1.7 To make sure that the 230 Vac/50 Hz standard GFIs (Ground Fault Interruptors) work.

Specific test requirements and procedural guidelines are included in PARA 5.2 through 5.6 following.

5.2 OVER AND UNDERVOLTAGE PROTECTION

5.2.1 UNDERVOLTAGE PROTECTION

Place the UV test switch in the "LO" position; this presents the undervoltage comparator (Voltage Sensitive Hybrid Switch) with a voltage that simulates a DC bus voltage of 44.4 volts (1.85 VPC @ 77°F)* or less. This is only an operability check. Now under a combined 15 Adc and $2A_{AC}$ load discharge the battery string with the least charge. A projective trip should occur to below 44.4 volts (1.8 V_{PC}). This test must be conducted with the GENSET DEMAND switch in the Manual Disconnect Mode, and the array circuit breakers CB-A & CB-B "OFF".

DOES THE SYSTEM SAFELY SHUTDOWN WHEN THE SELECTED UV POINT IS REACHED?
__✓__ YES; ______ NO; ACCEPTED ______

* The 1.85 VPC (volts per cell) end point is not necessarily "cast in concrete". The value finally selected may depend upon the load management strategy finally evolved as well as the prevailing conditions at the Earth station.

5.2.2 MAIN SYSTEM BUS OVER VOLTAGE

BACKGROUND

Abnormally high and probably destructive dc bus potentials would most likely result from a failed DCPS (battery charger), or a malfunctioned PV regulator. Either will force the batteries into gassing and a dangerous state from the standpoint of survivability. The GENSET, capable of delivering about 2.4 KW to the load and/or the battery would be the worst. Maximum permissible bus voltage of 62.4 Vdc (2.6 VPC) has been selected. As in the case of the undervoltage set point, this is open to review.

PROCEDURE

First place the OV test switch in a "HI" position. This presents the overvoltage comparator (VSHS) with a voltage simulating a bus of 62.4 Vdc or greater. This is an operability check. Now ensure of the following:

a) The the PV array simulators OFF & CBA/CBB are tripped.

b) That the PV regulators CHA and CHB are in the manual disconnect.

c) All three mode battery strings are disconnected.

d) That the AC source select is in the "GENSET SELECT" position.

e) The inverter switch is "OFF".

f) Establish a nominal dummy DC load of 60 Vdc @ 5 Adc. An AC load is not required. Now activate the GENSET DEMAND switch, leaving it in Manual Bypass ("ON"). The DCPS should support the DC bus after the GENSET has started up. Now adjust the voltage control know so that the bus voltage increases toward 62.4 Vdc.

At the threshold, a protective trip should occur, shutting down the GENSET and disconnecting and latching out all power generation circuits.

DOES THE SYSTEM PROPERLY SHUT DOWN AND ENTER A MODE WHERE ALL SUB-SYSTEMS AND THE ESL/CLASSROOM LOAD ARE ISOLATED?
_____ YES; _____ NO; ACCEPTED _____

5.3 OVERCURRENT PROTECTION

Overcurrent protection is provided by load and source circuit breakers in the PCC, by fuses in all battery loads, and by the overcurrent shutdown and protective devices incorporated at the factory in the ONAN GENSET. Breakers can be tripped by 150% overcurrent for several seconds; since they have an inverse time characteristic. The value of connecting overcurrent loads on the GENSET is questionable, for they, like the battery, are either fused or CB protected. A review of design in lieu of proof testing should determine the adequacy here.

OUT OF LIMITS CURRENT AND OTHER OC PROTECTIVE DESIGNS ACCEPTABLE?
_✓_ YES; ____ NO; ACCEPTED ______

5.4 **EMERGENCY STATE PROTECTION**

This requirement is covered by testing under PARA's 4.4 and 5.2 preceding. The system will of course self disconnect when the emergency button is pushed.

HAVE ALL PRACTICAL EMERGENCY SITUATIONS BEEN ADDRESSED?
_✓_ YES; ____ NO; ACCEPTED ______

5.5 **DC GROUND FAULT RELAYING**

A fault anywhere in the DC system involving inadvertant or accidental diversion of positive bus current to earth will trip the ground fault relay and crowbar the array providing:

a) the current exceeds 12 milliamperes.
b) the ground return path to neutral is established.

At 60 volts DC the potential danger to personnel is reduced but not sufficiently to preclude testing; a secondary purpose of the test is to clear any sneak grounds that may later develop into significant hazards.

To verify this capability, short the positive (+) bus to the Earth reference (grounding node) at any point.

DOES THE DC GFR WORK? ____ YES; ____ NO; ACCEPTED ______

5.6 **AC GROUND FAULT INTERRUPTOR**

These are standard 230 VAC 50 Hz industrial interruptors (UL recognized) manufactured by Square D. They have a test button, but should be further be tested by simulating a line-to-earth fault. Place a 2000 ohm, one watt insulated resistor in series with a "chicken stick" probe. Attach the grounding end to the local earth reference. Load the isolated end to the 230 Vac "hot" line to the classroom. Repeat for the maintenance bus.

DO THE GFR'S AUTOMATICALLY TRIP IN THE SUBSECOND TIME FRAME?

IN THE CLASSROOM LOAD BUS? ____ YES; ____ NO; ACCEPTED ______

IN THE MAINTENANCE BUS? ____ YES; ____ NO; ACCEPTED ______

6.0 **VERIFICATION OF INSTRUMENTATION CAPABILITIES**

6.1 **PURPOSE**

The purpose of this review is to ensure that the requirements of PARA 5.0 "Instrumentation and Alarm" of RFP 3409503 have been met in design and implemented in hardware. For this proof-of-design phase the following premises have been adopted:

a) That the detail final design review has resulted in the acceptance of the design and specified instrumentation hardware.

b) That factory certifications ("CERTS") and calibration data has been forwarded with each device.

c) That in-house quality control measures have controlled acceptance.

6.2 **COMPLIANCE**

DOES BUILT-IN INSTRUMENTATION AND ALARMS COMPLY WITH THE REQUIREMENTS OF PARA 6.1 PRECEDING? ____ YES; ____ NO; ACCEPTED ______

APPENDIX B

ACCEPTANCE TEST RESULTS

Final Test and Acceptance
for the
Stand-Alone Photovoltaic Power System
with Engine Generator Back-up
Wawatobi, Indonesia

This is to certify that the photovoltaic power system with engine generator back-up was inspected and tested in accordance with the attached plan and the system met or exceeded the physical and performance parameters.

Tester ______________________ 6-3-85
N. A. Marshall (Date)
Hughes Aircraft Co.

Acceptance ______________________ ______________
R. DeLombard (Date)
NASA Lewis Research Center

Acceptance ______________________ 6-3-85.
Perumtel, Indonesia (DATE)
Ir. Bambang RO
NIK 521922

APPENDIX B

Final Test and Acceptance

INTRODUCTORY COMMENTS

Subject APPENDIX "B" is an executed and witnessed final test and acceptance check-list, demonstrating that the installed Stand-Alone PV Power System for the Wawatobi Remote Satellite Earth Station did indeed satisfy contractual performance and design requirements.

As power system installation neared completion, it became apparent that the Final Test and Acceptance document generated at Hughes, Long Beach, and NASA Lewis was too complex, especially in the non-functional areas, such as structural appearance and related details. Perumtel also had a number of generalized comments and action requests with regard to physical arrangements that were beyond the scope of the specifications.

Accordingly, by mutual agreement of the Indonesia Perumtel Site Manager, the cognizant NASA Field Representative, and the Hughes Installation Task Leader, a condensed functional check-list was developed on site. This document covered every essential aspect of the governing functional specification, but avoided detailed write-up of test events, sequences and results. The executed copy following is that document.

It should be noted that the copy of the completion certification does not bear the authenticating signature of the cognizant NASA representative. His travel schedule was such that he witnessed the successful completion of testing only through functional system evaluation. Several days of training yet had to be completed, and instructions on VSHS (Voltage Sensitive Hybrid Switch) calibration procedures yet to be accomplished.

NASA project files should contain an earlier interim certification authenticated by all three signatories. The final document, herein attached, reflects also the completion of the two additional tasks, training, and control calibration.

SYSTEM START-UP

AND

SHUTDOWN

- ____ o Close the Battery Safety Switches (77), (78), (79).
- ____ o Test switches (18) through (24) on the PCP should all be in "OFF".
- ____ o Make sure all Mode Control switches (25) through (30) on the PCP are in "AUTO" except (29), GENSET DEMAND; this switch should be placed in MANUAL DISC.
- ____ o Go to PCP and push Control Power pushbutton switch (31). The light in control power switch (31), should glow orange. Reset UV/OV and Crowbar with reset P.B.
- ____ o Status lights CH-A (2) and CH-b (4) on the PCP should glow.
- ____ o Make sure AC Source Select Switch (16) on the PCP is in AUTO.
- ____ o All meters except the battery meters on the Instrument Panel (80 through 83) should read zero. On the PCP the battery ammeter (15), should be in the zero center. Meters (54), (55), 56), on POP should also read zero.
- ____ o Now close CB-1 (58) and CB-2 (59) circuit breakers on the POP.
- ____ o Meters on PCP (15) and (82) on Instrument Panel now should indicate between 2 and 10 amperes discharge.
- ____ o The Status Lights should read as follows: (2), (4) ON (Green); (1), (3), (5), (6), (7), (8), (9), (10), (11), (12): OFF.
- ____ o Now close PV Array Circuit breakers CB-A (52) and CB-B (53) on the PSM.
- ____ o Unless battery is almost fully charged, Lights (2) and possibly (4) will stay ON (Green).
- ____ o On the POP, move CB-2 (60) to the CLOSED position.
- ____ o On the POP, meter Vrms (54) should indicate 230 VAC; frequency meter (56) should indicate 50 Hz; ammeter Irms (55) depending upon the AC load it may indicate in the several ampere range.
- ____ o Meter (80) on the Instrument Panel should indicate PV array current, which might be as high as 25 amperes.
- ____ o Ammeter (15) on the PCP should have moved to right, showing that some charging current is available.
- ____ o Meter (82) on the Instrument Panel indicates the DC load current. The sum of the DC load current and the battery charging (81) current should almost equal the PV array current (80).
- ____ o Meter (83) on the Instrument Panel displays DC bus voltage, which should be greater than 52 volts if any sunlight is falling upon the PV Array.

- o Immediately turn on the DC Battery Charger by setting circuit breaker (31A) to "UP".
- o Now set PCP GENSET DEMAND Mode Control Switch (29) to Bypass (ON). After about a one minute delay period, the GENSET should start.
- o Current will now flow from both the PV Array and the Battery Charger to the load and to the battery.
- o The GENSET to power the AC load, turn the AC Source Select Switch to "GENSET".
- o GENSET output may now be read on meters Vrms (54), meter Irms (55), and frequency meter (56).
- o The Status Lights on the PCP will now read as follows: (1), (3) Amber ON; (2), (4), (5), (6), (7), (8), (11), "OFF"; (9), ,(10), (12) White ON.
- o On the PCP, return the GENSET DEMAND Mode Control Switch (29) and the AC Source Select Switch to AUTO. The GENSET should shut-down and the system should continue to run on PV Array alone if the intensity of the sunlight is sufficient.
- o Go to Alarm Box and turn switch (111) to On. Check fluorescent light operability.
- o System operations can now be checked by observing the meters on the Instrumentation Panel.
- o Ammeter (80) on Instrumentation Panel, should be reading the PV Array current up to about 25 ADC. The Battery Charger ammeter (81) is read when the GENSET is ON and will read as high as 20 amps with a low battery state of charge.
- o Ammeter (82) on Instrumentation Panel reads DC load current drawn by the Earth Station.
- o Voltmeter (83) may read as high as 60 volts if the Battery is charging. It may read as low as 46 volts if the Battery is heavily discharging.

SHUTDOWN

After properly operating, the power system may be shut down in the following sequence:

- o On the PSM open CB-A and CB-B circuit breakers, (52) and (53).
- o On the PCP place the GENSET DEMAND Mode Control Switch (29) in UP/MANUAL DISC.

- ____ o Press to turn OFF CONTROL POWER Pushbutton Switch (31); all control power should be OFF. All panel display lights should be off except the PV power indicator.
- ____ o On the POP open (place in the down position (CB-1 (58), CB-2 (59), CB-3 (60) and CB-4 (61).
- ____ o Turn Battery Safety Switches (77), (78), (79), to OFF.

EMERGENCY SHUTDOWN

- ____ o An EMERGENCY SHUT-DOWN SWITCH is prominently installed on the right side of the Power Controller Cabinet. In the event of an emergency, quickly depress this large pushbutton switch and then open the three battery safety switches (77), (78), (79). Call troubleshooting and repair personnel immediately.
- ____ o Demonstrate proper operation of control system by use of test/mode control switches, and calibration of voltage sensitive switches.
- ____ o Training activity successfully completed.

EXCEPTIONS

1. One string of 8 three cell batteries were damaged beyond repair by electrolyte loss in shipping. These will be replaced by insurer.
2. The 500 watt Freedom Inverter originally in the Hughes Power Controller does not work. It will be replaced under warrenty.
3. Replacement control relays and faulty Ground Fault Interruptor will be provided.
4. Hughes will instruct Silkar to review proposed remedial (corrective) action to relieve horizontal driving rainfall problems and estimate costs. Hughes recommends against serious restriction of air ventilation.

GENSET TEST

ONLY

<u>GENSET ONLY Operation</u>

In the event of a battery and/or a power controller malfunction the GENSET may be used to directly power the Earth Station loads. This accomplished by taking the following steps:

______ o On the PCP turn off control power by pressing Control Power pushbutton switch (31).

______ o Open the three Battery Safety Switches (77), (78), (79).

______ On the PCP place AC Source Select Switch (16) in "GENSET" mode.

______ o On the PCP place Mode Control Switches (25), (26), (27), (28), (30), in MANUAL DISC.

______ o On the PSM turn OFF CB's.

______ o On the PCP place GENSET DEMAND Mode Control Switch (29) in BYPASS (ON/DOWN) position, thus starting the GENSET.

______ o On the POP close circuit breakers (CB-3 (60), CB-4 (61). The system is now completely on direct GENSET power.